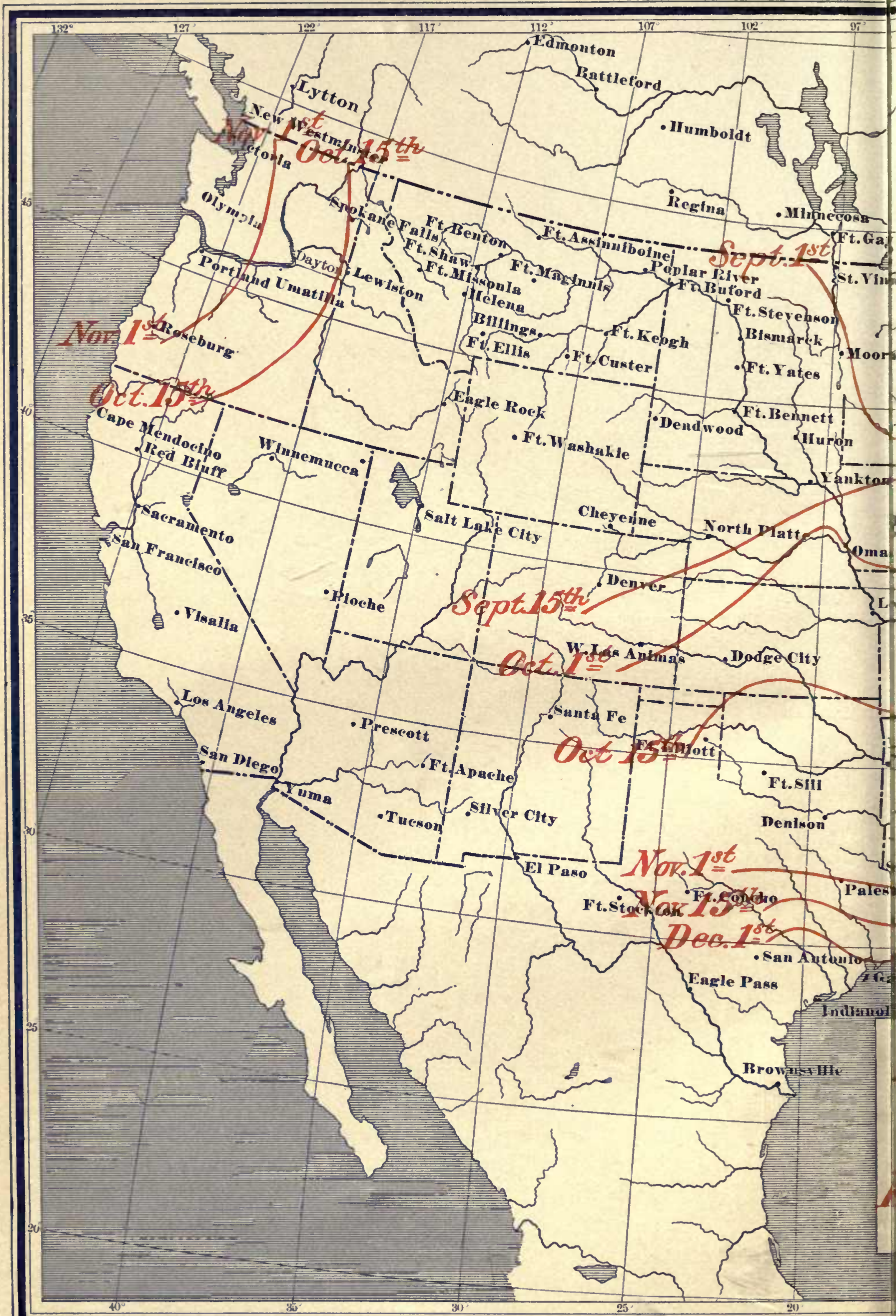

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Humboldt
Lytton
New Westminster
Victoria
Regina
Minnecosa
Olympia
Spokane Falls
Ft. Benton
Ft. Assinniboine
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Poplar River
Ft. Buford
Helena
Dayton
Lewiston
Portland
Umatilla
Ft. Stevenson
Bismarck
Roseburg
Billings
Ft. Keogh
Ft. Ellis
Ft. Custer
Ft. Yates
Eagle Rock
Ft. Bennett
Deadwood
Huron
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Yankton
Sacramento
Salt Lake City
Cheyenne
North Platte
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Prescott
Santa Fe
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Tucson
Denison
El Paso
Ft. Concho
Ft. Stockton
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Father Pt.
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Sidney
Halifax
Quebec
Prince Arthur's Landing
Rockliffe
Montreal
Eastport
Duluth
Marquette
Parry Sound
Burlington
Mt. Washington
Yarmouth
Mackinaw City
Escanaba
Alpena
Portland
St. Paul
Sangeen
Toronto
Kingston
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
Milwaukee
Detroit
Erie
New Haven
New Shoreham
Dubuque
Chicago
Toledo
Williamsport
New York
Sandy Hook
Des Moines
Davenport
Sandusky
Cleveland
Pittsburgh
Philadelphia
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Atlantic City
Del. Breakwater
Springfield
Cincinnati
Washington
Chincoteague
St. Louis
Louisville
Lynchburg
Norfolk
Springfield
Cairo
Kittyhawk
Hatteras
Nashville
Knoxville
Charlotte
Memphis
Chattanooga
Wilmington
Smithville
Little Rock
Augusta
Starkville
Atlanta
Vicksburg
Montgomery
Savannah
Pensacola
New Orleans
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
92°
87°
82°
77°
72°
67°
62°
57°
15
10°
5°
0°
5°

AMERICAN WEATHER.

A POPULAR EXPOSITION OF

THE PHENOMENA OF THE WEATHER,

INCLUDING CHAPTERS ON

HOT AND COLD WAVES, BLIZZARDS, HAIL-STORMS AND TORNADOES,

ETC., ETC.

ILLUSTRATED WITH 32 ENGRAVINGS AND TWENTY-FOUR CHARTS.

BY GEN. A. W. GREELY,

Chief Signal Officer, United States Army.

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PUBLISHERS.

PREFACE.

THE object of this work is to give clearly and simply, without the use of mathematics, an idea of meteorology in general, supplemented by climatic data regarding temperature, rainfall, wind, and storms, especially of our own country.

The examples cited in most modern works are, in great part, drawn from foreign sources, so that the author has felt the advisability of setting before the American public in some detail the fact that there can be found in the United States all varieties of weather. The delightful climate of the Riviera, the burning heats of the Sahara, and the eternal frosts of Siberia find their parallels within the broad confines of our Union.

The violence of our tornadoes and hurricanes, the extremes of heat and cold, the absence of rain or its enormous superabundance, the number of storms, and the size of hail-stones, together with the prolonged heated terms of summer and the phenomenal and extensive cold waves of winter, prove that one need not quit America to experience the most wondrous action of nature's forces.

Ferrel's elaborate and mathematical treatise on meteorology covers very fully the scientific field at the present time, but the author knows of no plain and simple American book, other than that of Loomis, which that distinguished meteorologist has not rewritten in the light of our present knowledge.

The author acknowledges his indebtedness to the valuable memoirs and publications of Abercrombie, Blanford, Buchan, Loomis, and Scott. He has also utilized the official writings and publications put forth by the Army Signal Office. No great claim for originality is set forth, although the author has supplemented and modified the statements and opinions of other meteorologists and occasionally advanced new ideas, the result of his many years of study and practice in meteorological work, and of his personal labors as a predicting officer.

The thanks of the author are due for timely suggestions to Professor Thomas Russell, who has rendered valuable aid in correcting the proof-sheets.

A. W. GREELY.

WASHINGTON, October 1, 1888.

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AMERICAN WEATHER.

CHAPTER I.

INTRODUCTORY.

From the beginning of time the alternation of the seasons and the irregular recurrence of weather conditions must have interested man and engaged his attention. The very ancient Book of Job and the later books of the New Testament contain formulated weather wisdom, the result of man's primitive observations. The ancient classical writers dwelt much on weather phenomena, but owing to ignorance of physical laws, made no substantial advances in formulating them.

The invention of the air-thermometer near the end of the sixteenth century (by some attributed to Sanctorio, of Padua, 1590), and of the barometer, by Torricelli, in 1643, afforded the first reliable means of instrumental observations of the temperature and pressure of the air. It is only within the last hundred years that the acute and remarkable meteorological essays of Dalton awakened the attention of scientific men to the fact that the principles of philosophy were sufficient to explain the intricate and varied phenomena of the atmosphere. Since the beginning of the century very much has been done to lay the solid foundations of meteorology as an exact science by amassing data, formulating conditions, disproving unsound theories, and in evolving a few general laws.

The theory of dew, the exact relation of winds to varying atmospheric pressures, the deflecting influence exerted by the rotary motion of the earth, and the gyratory system of storm winds are doubtless the most important subjects, whose elucidation has enriched theoretical meteorology during this time.

The term meteorology originally included astronomical phenomena, but by common consent it now relates only to weather and climate. In this work the writer intends to discuss more particularly the climatic conditions of the United States, treating of the weather conditions only so far as may be needful to set forth the subject simply and generally.

The average composition of *dry* atmospheric air, according to Ferrel, consists of oxygen by volume 20.95, and by weight 23.16 per centum ; nitrogen, 79.02 volume, 76.77 weight ; carbonic acid, 0.03 volume, 0.046 weight. In addition to these main constituents, measurable quantities of ammonia, ozone, and traces of carburetted and sulphuretted hydrogen, nitric and sulphurous acids also exist. The atmosphere, however, is never entirely dry, but contains water in the shape of aqueous vapor, which is irregularly distributed in largely varying quantities.

The actual height of the atmosphere is assumed to be about two hundred miles above the surface of the earth, but the rarefaction of the air increases so rapidly with elevation that seven or eight miles is about the limit at which mammals or birds can live. Sir James Glashier, September 5th, 1862, ascended in a balloon from Wolverhampton, England, to about the height of seven miles, and barely escaped death.

Although it is uncertain whether the constituents of the atmosphere are equally distributed, yet, as observation shows no material difference at great elevations, it has been assumed that continually ascending and descending air currents cause the proportion of gases to be substantially constant throughout the different air strata.

The determination of the exact physical conditions of the atmosphere involves the ascertaining by instruments of its temperature, its pressure, the amount of evaporation or condensation of aqueous vapor—whether invisible or in the form of clouds, rain, etc.—and the amount of transference from one point of the earth's surface to another, as indicated by prevailing winds or the silent, but no less important, movement of the mercurial column. In addition may also be noted the quantity and kind of atmospheric electricity, the amount of ozone, the manifestations of the aurora, and the presence or absence of meteors and various optical phenomena, such as halos, coronas, etc. The manifestations of terrestrial magnetism, formerly conjoined with meteorology, should no longer be considered except as a separate branch of the physical sciences.

The abiding interest in meteorology displayed by the people of the United States results from the more or less successful efforts to determine from instrumental readings and observations the special conditions that indicate the development, advance, and progress of the atmospheric disturbances, which, resulting in storms of greater or less violence, cause enormous destruction of property and often considerable loss of life.

Theoretical meteorology involves a careful consideration of all phases of such disturbances, even the most minute, since any theory of weather predictions based on other than sound reasonings and an accurate study of physics must be considered one of the worst forms of empiricism. The spirit of the day especially demands, however, that scientific research shall show the widest range of practical results, and so all systems of weather predictions and storm warnings should be supplemented by the taking and collating of such observations as may lead to a thorough knowledge of that local sanitary meteorology so important to the welfare of great cities, and as to the fitness of local climates as a means either of extending the scope and extent of national industries or of alleviating human suffering and saving human life.

CHAPTER II.

THE ATMOSPHERIC PRESSURE, AND HOW MEASURED.

THE pressure of the atmosphere on the earth is measured by a barometer, either mercurial or aneroid, the readings of which give the air pressure expressed in inches of pure mercury. For instance, the reading 29.92 indicates that the weight of the air (with its aqueous vapor, etc.) over that part of the earth is equal to the weight of a layer of mercury of the depth of twenty-nine and ninety-two hundredths inches.

The pressure of an atmosphere, considered as a unit, is the weight of a column of pure mercury at a temperature of 32° * at the height of 29.92 inches (760 mm.), in latitude 45°, at the level of the sea.

The pressure of the air in the United States at the level of the sea is about 14.7 pounds on each square inch of surface. As the elevation of the land above the mean sea-level increases, the pressure of the air decreases; and since the specific gravity of mercury is 13.60, the pressure of the air at any elevation can easily be determined from the height at which the mercury stands in the barometer.

The principle of the barometer is the well-known and simple one on which depends the action of the common pump—viz., that a tube filled and sealed at one end and inverted into liquid such as the tube contains

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* All temperatures in this work are in degrees Fahrenheit, except when marked C. (Centigrade).

empties only partly, owing to atmospheric pressure being exerted only on the exterior surface.

A glass tube of uniform bore, three feet long and half an inch in diameter, filled with pure mercury, best answers for the purpose of measuring the atmospheric pressure. The tube before being filled must be carefully dried, since any moisture remaining in the vacuum at the top of the tube would be converted into aqueous vapor, which, when present, presses downward on the top of the column with a force varying with the temperature, and causes the mercury to sink too low. The mercury moving freely in the tube is in equilibrium with the weight of the atmosphere, and its surface ascends or descends as the pressure increases or decreases. Near the level of the sea pure mercury usually descends until its height is about thirty inches above the surface of the mercury in which the tube is plunged.

The barometer in general use is a straight glass tube securely fixed, with a scale permanently attached thereto. Fortin's device, which is now applied to all standard barometers, consists in raising or lowering the mercury in the cistern, by a screw, until its surface is brought to the level of an ivory point, which serves as the zero of the scale. It is not convenient to have a scale extending the whole length of the barometer. Usually a short scale, covering the range of extreme fluctuation, is securely fastened to the metal casing which surrounds the glass tube.

This casing in an improved standard barometer (see Fig. 1) consists of a brass tube terminating at top in a ring for suspension, and at bottom in a flange to which the cistern is attached. The upper part of this tube is cut through so as to expose the glass tube and mercurial column within. Attached at one side of this opening is a scale, graduated in inches and parts, and inside this slides a short tube, connected to a rack-work arrangement, moved by a milled head; this sliding tube carries a vernier in contact with the scale, which reads to .010, and in some cases to .002 inch.

In the middle of the brass tube is fixed a thermometer, the bulb of which, externally covered but inwardly open and nearly in contact with the glass tube, indicates the temperature of the mercury in the barometer tube. This central position of the thermometer is selected that the mean temperature of the whole column may be obtained—a matter of importance.

The cistern is made up of a glass cylinder, which allows the surface of the mercury to be seen, and a top plate, through the neck of which the barometer tube passes and to which it is fastened by a piece of kid leather, making a strong, flexible joint. To this plate, also, is attached a small ivory point, the extremity of which marks the bottom or zero of the scale above. The scale is laid off in England and America in English inches—the height of which is very carefully determined with reference to the zero point. The scale covers a range of four inches or more, usually from twenty-seven to thirty-one inches when to be used near the level of the sea. A screw serves to adjust the mercury to the ivory point, and

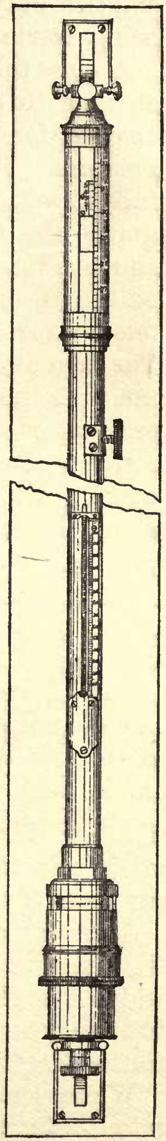


FIG. 1.
Standard Barometer.

also by raising the leather bag, which forms the lower part of the cistern, contracts and completely fills the tube and it with mercury, and puts the instrument in condition for transportation.

The tube is sometimes bent in the form of a siphon, in which case the height of the mercurial column is measured with reference to the surface of the mercury, at the open end. Siphon barometers are frequently used for automatic registration, and in such instruments the zero of the scale is movable.

The fixed scale is usually divided to tenths of inches, but to insure greater accuracy, a movable scale, called a vernier, is arranged so it can be moved up and down the fixed scale with ease and precision. The vernier has ten principal divisions, which are exactly the same length as nine divisions of the fixed scale, so that each vernier division is just one tenth less than a scale division, or equivalent to 0.010 inch. The observer reads on the fixed scale the inches and tenths of inches *next below* the *lower* edge of the vernier, and from the vernier itself reads off the hundredths of inches, which are found by noting the vernier line which exactly or most nearly coincides with a scale division. If the marks coincide the reading is even hundredths, and a zero can be put in the place of thousandths ; but if, as generally happens, no vernier mark coincides *exactly*, the thousandths of an inch can be estimated.

Some barometers have—a preferable arrangement—the fixed scale divided to twentieths of an inch, in which case the vernier has twenty-one divisions, equal to twenty on the scale, and the reading is made directly to the nearest thousandth of an inch.

While persons of ordinary intelligence can in a few minutes learn how to read a barometer accurately, yet to insure satisfactory observations the observer must not only be careful and methodical, but also should understand the various sources of error and the means of correcting them.

The instrument should be vertical and the temperature—to be kept as equable as possible—first be determined; the cistern mercury under a good light and exactly level with the zero point; the vernier set so that its front and back edges are just tangent to the *meniscus*, or rounded top of the mercury surface, while the eye should be at the same height. Readings both of the attached thermometer and vernier should be verified after being recorded, and to insure greater accuracy it is advisable to mentally calculate the change since the last reading, and if unusual, to make a second reading.

It is well to correct two popular but erroneous ideas regarding the location and the observed reading of the barometer. It is not necessary that the instrument should be situated out of doors, since the atmospheric pressure is the same in the house. Again, the words "fair," "change," "stormy," which appear on the scale of many barometers, have no special significance, except for some particular locality, and, indeed, are often misleading. The continuance of fair or stormy weather, or the change from one to the other, is betokened by the fluctuations and not by the mere height at which the mercury stands.

Corrections must be applied to all barometer readings in order that those of different instruments may be strictly comparable with each other, and so be readily used for scientific purposes. Some corrections have reference to the special instrument, while others are of general application.

The correction for instrumental error is applied to reduce the readings of an individual instrument to any particular standard. It is additive (+) if the barometer reads too low, or subtractive (—) if it reads too high.

CORRECTION FOR CAPILLARY ACTION.

The correction for capillarity is always additive, since barometers are affected by the capillary action between the glass tube and the mercury, the effect of which is constantly to depress the mercury by a certain quantity nearly inversely proportional to the diameter of the tube.

This depression is greater in tubes in which the mercury has not been boiled than in those which have been subjected to this process. The amount of this depression in boiled tubes, according to Buchan, is as follows: If the diameter of the tube is 0.1 inch, the depression of mercury is 0.070; if 0.2 inch, 0.029; if 0.3 inch, 0.014; if 0.5, 0.003 inch. Most makers allow for this by depressing the scale in each barometer just sufficient to offset the capillary action.

Certificates furnished generally include the corrections above mentioned, as far as any of them are applicable to that special barometer.

CORRECTION FOR TEMPERATURE.

In consequence of the great risk of the heat of the observer's person affecting the thermometer attached to the instrument during the process of taking a reading of the barometer, the attached thermometer, as has been said, should always be recorded before the reading of the barometrical column is made. As is well known, all bodies are affected in their dimensions by heat, and in taking accurate measure of any object, it is necessary to know at what temperature the measure was made, in order to determine what the length would have been at some definite standard temperature.

The very considerable changes in the volume of mercury, caused by varying temperatures, renders it necessary for purposes of comparison that the height of a column should be reduced to a standard temperature. By common consent of physicists this standard is 32° (0 C.)—the temperature of melting ice. The amount of this correction is about 0.0027 inch for each degree Fahrenheit. For convenience, tables have been calculated from which the proper corrections can be obtained by inspection. (See Table 1, Appendix.) It will be noticed that the minus correction does not stop at 32°, but extends down to 28° (—2 C.), since the scale in general use, and considered the best, is of brass, and its inches, which have their true length at a temperature of 62°, are too short at 32°, owing to the contraction of the metal. If the scale is of glass, iron, or wood, different corrections are required, depending on the different coefficients of expansion.

CORRECTION FOR ALTITUDE OR REDUCTION TO SEA-LEVEL.

As we ascend in the atmosphere the air pressure gradually diminishes and the barometer reads lower. In order to make barometer readings comparable at stations of different elevation, it is necessary to reduce them to a common plane—usually the sea-level. This reduction depends upon the temperature of the outside air as well as the height of the station. It is important to obtain accurately the elevation of the barometer above sea-level. If it is impossible to get the correct elevation, an approximate value may be computed by means of barometric observations at the station compared with those made at the same time at a neighboring station, the elevation of which is known. Table No. 2 gives the reduction for barometer readings at stations up to 1500 feet.

The mercury in the Fortin barometer is liable, in course of time, to oxidation. The instrument can be safely inverted and the cistern opened by a skilled and careful person. The oxide is readily separated by means of a cone of clean white paper, the pure mercury passing readily through the tiny hole at the apex.

Barometers should never be moved, even a few feet, except after screwing up the cistern until the mercury quite touches the top of the tube. The instrument can then be safely inverted and with moderate care transported, without injury, to any distance. After such removals the vacuum should be tested. If it is quite perfect and free from moisture and air, the mercury when the tube is suddenly tipped strikes the top with a sharp, clear sound.

An inverted siphon tube filled partly with air and partly with glycerine, called the sympiesometer, was formerly much in use as a cheap weather glass. Its indications are uncertain and untrustworthy, while the instrument easily becomes unserviceable, so that it is now rarely used.

THE ANEROID BAROMETER.

Although the mercurial is considered the standard barometer, yet aneroid and metallic barometers have great advantages, owing to their extreme portability and adaptability for self-registration, and when compensated and well made are most valuable substitutes for the mercurial form of instrument.

The principle of the metallic (Bourdon's) barometer is somewhat similar to that of the aneroid. These instruments have come into extensive use, owing to their cheapness and convenient method of reading. The aneroid is especially suitable for seafaring persons employed in boats or small vessels, where mercurial barometers cannot be satisfactorily used.

A small hermetically sealed metallic box, from which all the air has been exhausted, and a heavy spring, to which the top of box is attached, are the principal parts of the aneroid barometer. Its index is moved by a combination of levers connected with the top of the vacuum chamber, which, having a very thin top, is raised up by the spring when the pressure of the atmosphere decreases and is forced inward when the pressure increases.

The instruments are graduated experimentally, as they do not measure pressure absolutely, but afford indications relative to a mercurial barometer.

Unfortunately, even aneroids of the best workmanship do not remain accurate, owing to deterioration of the metals used. Either rust, corrosion, or the weakening of the springs or levers, resulting from a permanent set, is sufficient to render the readings erroneous in time, while rough usage almost invariably does so at once. Frequent comparisons with standard mercurial barometers are therefore necessary to insure the continued accuracy of the aneroid.

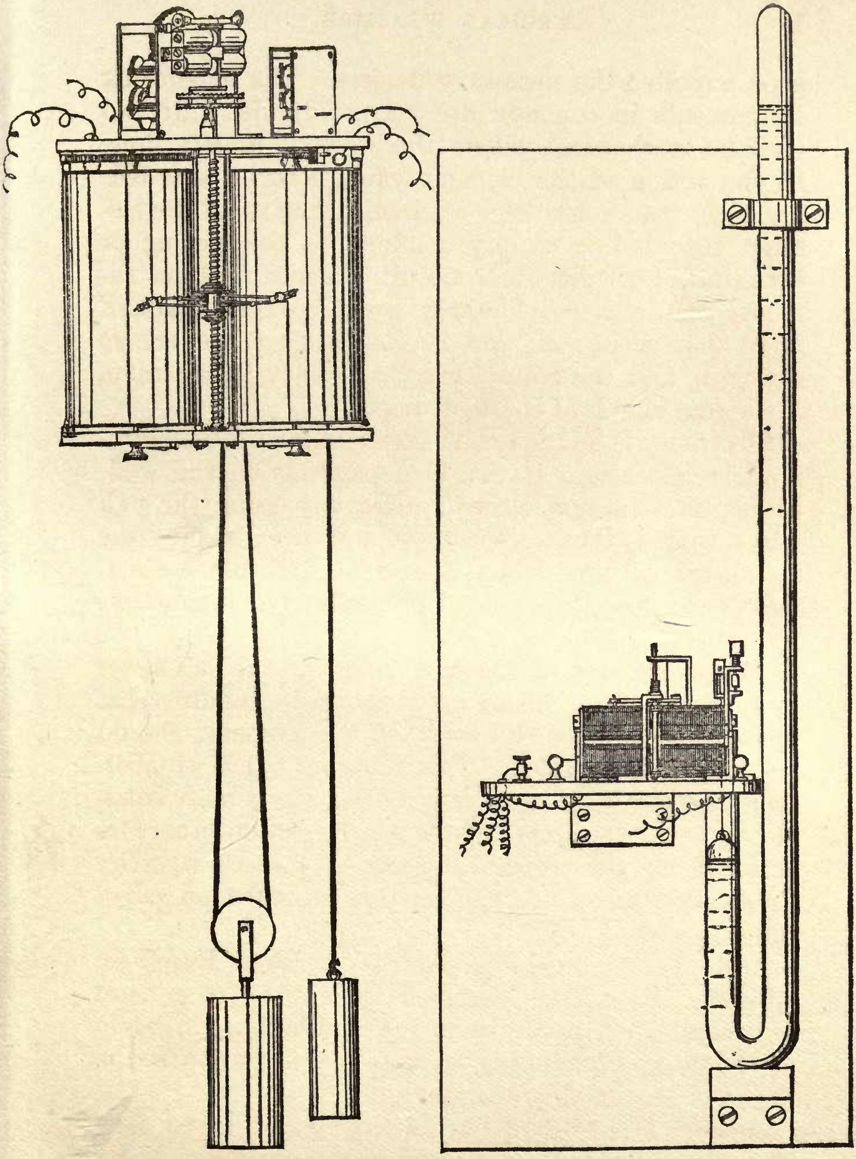
The importance and utility of self-registering meteorological instruments have long been evident, and the active minds of inventors have, to a considerable degree, supplied the necessary devices. The registering instruments in common use may be divided into two classes: mechanical, where the work is largely done by the action of the element which is to be recorded, and electrical, where the mechanical action of the element recorded is simply confined to the closing or breaking of an electrical circuit. Mechanical instruments require a considerably greater expenditure of force than electrical, and in consequence are not so sensitive, and the record has a tendency to lag upon the actual march of the instrument.

Electricity is an important factor in facilitating automatic registration, its value depending on the well-known fact that an electric current, passing through wires wound about a piece of soft iron, makes the metal, for the time being, a magnet, and that a cessation of the flow of electricity immediatelydemagnetizes the iron.

The registration of the movements of the barometer by photography to insure great accuracy, requires that the temperatures of the attached thermometer should also be photographed. This method, being cumbersome and costly, is very rarely used, since more satisfactory and almost as reliable results can be otherwise obtained by mechanical or electrical means, whereby the oscillations of the mercury are recorded on paper ruled to scale.

A number of ingenious devices in use at European observatories fail to commend themselves to general use, since their indications are marked upon plain paper, thus necessitating measurements to obtain the time and height of the barometer.

Among the mercurial barometers registering by electricity, the most satisfactory which have fallen under the writer's notice are Gibbon's, Hough's, Eccard's,



Transmitter. Barometer.

FIG. 2.—ECCARD'S TRANSMITTING BAROMETER.

and Draper's. Gibbon's and Hough's instruments depend upon a common principle, wherein the use of the siphon form of the barometer is necessary. A small float in the short arm of the siphon is connected by a thread with the short arm of a light pivoted lever, which has the end of its long arm separated about a sixteenth of an inch from platinum points immediately above and below it. Whether the mercury rises or falls in the short arm of the siphon, the movement of the float causes an opposite movement in the direction of the long arm of the lever, which consequently touches either the platinum point above or below it. The moment the lever touches either platinum point, an electrical circuit is completed, and the action of the armature of the magnet moves a ratchet-wheel, which, by gearing, raises or lowers, as the case may be, the counterbalanced lever until it no longer touches the platinum points and the circuit is broken and the magnet made inactive. At the same time a different set of geared wheels raises or lowers, to the same proportional extent, a pencil which traces the record on an upright revolving cylinder, to which a paper with an exaggerated scale is attached. The records obtained from such instruments show in a strikingly graphic and quite accurate manner the barometric fluctuations. It is practicably impossible, however, to keep the mercury of the barometer at a uniform temperature, so that for readings of great accuracy such records are not entirely satisfactory.

Eccard's transmitting barometer, Fig. No. 2, sometimes has a duplicate set of magnets and another electric circuit, by means of which a second record is made at any convenient distance.

The Draper self-recording mercurial barometer consists of a glass tube in a fixed position, while the cis-

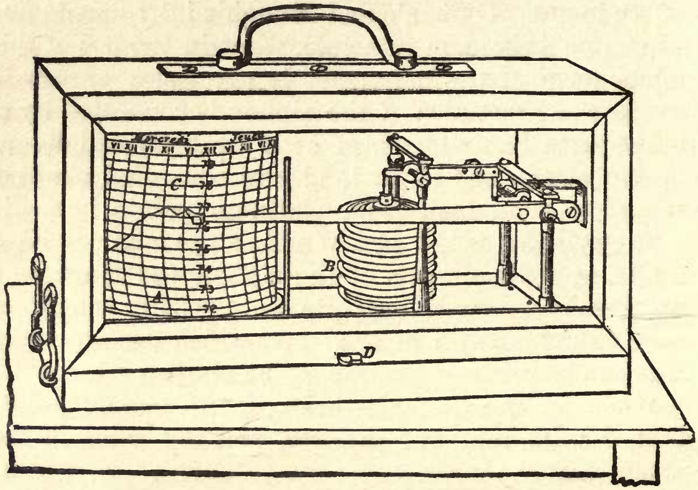


FIG. 3.—RICHARD'S SELF-REGISTERING ANEROID BAROMETER.

tern or reservoir in which the lower end of the tube dips is suspended by two steel springs with an attached pencil, which moves up or down the paper (which is ruled to scale) as the mercury flows in or out of the tube when the pressure increases or diminishes.

The "Richard" self-registering aneroid barometer, shown in Fig. 3, consists of a cylinder, A, on which the recording paper is wound, revolving once a week by means of a clockwork; a series of metallic boxes, B, eight in number, screwed together and exhausted of air; a compound lever, by means of which the motion of the top of the metallic boxes is transmitted, magnified about forty times, to the marking pen, C. As far as vacuum is concerned the shells are independent of each other.

The instrument is compensated for temperature. This is accomplished by leaving a sufficient quantity of air in one of the shells, ascertained by experiment when the instrument is made, so that with a rise of temperature the tendency of the barometer to register too low on account of the expansion of the levers and other parts is counteracted by the increased pressure of the air in the shell. The instrument, however, should be kept at a uniform temperature.

The cylinder can be turned and adjusted within small limits, so as to make the time scale correct by lifting it up after loosening the nut inside of it. The paper is ruled horizontally 0.05 of an inch apart, and the readings can be made to the nearest hundredth.

When the sheet is to be changed the pen is released from contact with the paper by pushing the lever, D, to the right.

When the instrument is first set up at a place, or a new sheet is put on, the pen is made to mark, within 0.02 inch, the pressure at the place, corrected for temperature and instrumental error. This adjustment is made by raising or lowering the whole series of aneroid boxes by means of a key. This adjustment is apt in time to change a little, there being a constant tendency for an aneroid barometer to read too high.

The mean daily pressure is obtained from twenty-four hourly observations. The diurnal variation of the barometer is so great and varies so from local causes, as will be shown in a later chapter, that a long series of observations is necessary to determine the corrections to be made in order to reduce the readings of any hour to the true daily mean. In table No. 3 will be found approximate corrections to reduce such readings in the United States.

CHAPTER III.

TEMPERATURE OF THE AIR.

The temperature of the air is not only scientifically the most important meteorological element, but it is also the one which most strongly affects the comfort and appeals to the attention of mankind. The thermometers in common use for obtaining air temperature are of spirits (alcohol) or mercury, and are known as dry (or standard), wet, maximum and minimum.

Thermometers sold at a low price, without the name of a trustworthy maker, should not be used for exact observations. Many cheap instruments have the scales made on a uniform pattern, the tube being attached thereto so that some single point of its scale may coincide with the correct degree mark. Not infrequently the errors of these thermometers are not greater than one or two degrees at temperatures between 32° and 60°, but owing to constrictions or irregularities in the diameter of the bore, the errors often are as great as five or even ten degrees at temperatures below zero, or above 100°.

Mercury presents most obvious advantages for thermometric use, since its qualities are such that little heat derived from exterior sources is absorbed, while almost the entire amount is rapidly transmitted and expands the entire mass. In other words, mercury has high conductivity, low specific heat, and a nearly constant coefficient of expansion through about seven hundred degrees, its range of fluidity. Below the point at which mercury freezes (—37.9° F., as determined by the late Dr. Balfour Stewart), it is necessary to use other thermometers—generally those filled with pure alcohol or spirits of wine. The use of spirit thermometers is not recommended except at low temperatures and for minimum readings, since the spirits of wine acquires the temperature of the air slowly, and its coefficient of expansion is somewhat irregular. Chloroform, ether, and bisulphide of carbon have been suggested as possibly suitable substitutes for alcohol, as a thermometric fluid.

For temperatures above —35° (F.) the mercurial thermometer is preferable. It should have a small cylindrical bulb, with sufficiently small tube to allow of a long enough scale to be graduated for the greatest possible range of temperature in the locality where it is to be used. In general, north of the 39th parallel in the United States the scale should be graduated from —38° to 115°, while to the southward of that parallel the range should be from —20° to 130°.

The thermometer bulb should be filled two years before being used, so that the molecular changes in the glass, which are so productive of errors, should take place before the graduation. The instrument should be tested, after filling, at some recognized observatory, and the errors should be determined for every ten degrees from 92° to —37.9° (F.), the temperature of freezing mercury. Thermometers of the United States Signal Service are usually tested from 102° to —28°, but for special alcohol thermometers, for use at inland northern stations, the tests are carried to —58°. The best thermometers should not have errors greater than 0.3°, nor should the change of error in ten consecutive degrees be greater than this.

Errors arise from the bore changing its diameter from point to point, unless suitable allowance is made for this in the graduation, by putting the marks closer together in some places and farther apart in others. This process is called calibration. A small part of the contents of the tube is made, while at a constant temperature, to occupy different parts of the tube. Its varying lengths in different places indicate how the graduations should vary.

The "freezing point" (32°) of a mercurial thermometer continually changes, although slightly, rising with age and lowering after exposure to unaccustomed high temperatures. Mercurial thermometers eight years old have been found to have the freezing point 0.6° too high, the greater part of the changes probably occurring the first year.

The necessity of comparisons is shown by the fact that many expensive alcohol thermometers from a maker of high reputation have been found to read four or more degrees too low at −30°, and in one instance twelve degrees too low at −58°. One case is known where a mercurial thermometer with a Kew certificate read two and one tenth degrees high at 62°, and an alcohol instrument of American manufacture read over twenty degrees too low at −60°.

The depression of the freezing point of a thermometer from exposure to unusually high temperatures, say 212°,* range from 0.1° to 0.8°, being greatest when the glass contains about 14 per centum of potash and the same amount of soda, and least when either of the foregoing constituents is entirely replaced by lime. This depression is temporary, and the instrument slowly recovers its normal condition, the return being the

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* Somewhat above 212°, however, the action reverses, and at 630° (350° C.) the freezing point is *raised* from 12° to 24°.

more rapid as the tube is older. Conversely, exposure to unusually low temperatures raises this freezing point, though very slightly, $-30°$ only two tenths.

The temperature of melting ice diminishes very slightly with increasing pressure, about one degree F. only for sixty atmospheres. But the mechanical effect of sixty atmospheres on the bulb would be to increase the readings of a thermometer about thirty degrees.

To test thermometers at temperatures above 32° (zero C.) water should be used; from 32° to $-40°$ alcohol cooled by surrounding mixture of ice and salt, or ice and muriatic acid or liquid ammonia. At temperatures below $-40°$ the cooling is effected by liquefied nitrous oxide.

Two thermometric scales are in common use, Fahrenheit and Centigrade (Celsius), while that of Reaumer has been extensively used in the near past.

The Reaumer graduation, in which 80° marked the interval from zero at melting ice to 80° at the boiling point, is now rarely used. For convenience of conversion it is stated that four degrees Reaumer equals five degrees Centigrade, or nine degrees Fahrenheit. In converting, it should be borne in mind that the zero of Reaumer corresponds to 32° Fahrenheit.

The Centigrade scale is in general use, except in English-speaking countries where Fahrenheit is employed. Zero Centigrade represents melting ice, generally known as the freezing point, while the boiling point of water marks 100°. In the Fahrenheit scale these two points represent respectively 32° and 212°.*

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* The boiling point of Fahrenheit's thermometer is very slightly lower than the boiling point on the Centigrade scale, since the former is based on an atmospheric pressure of 29.905 inches at London, and the latter one of 760 mm. (29.922 inches) at Paris. Reduced to standard gravity

To convert Fahrenheit readings into Centigrade, subtract 32, multiply the remainder by 5, and divide the product by 9. To convert Centigrade to Fahrenheit multiply by 9, divide the product by 5, and add to the result 32.

All readings below the zero of these three scales are prefixed by a minus sign. Since the zero point of the Centigrade thermometer coincides with frost, or the freezing point, it is common in Europe to speak of the minus readings, Centigrade, as so many degrees of "frost." From this convenient method has arisen an inaccurate one in England of classing readings on the Fahrenheit scale in a similar manner, so that at times it is doubtful whether the person using the term has in mind a reading that number of degrees below the freezing point or below zero Fahrenheit. The zero of Fahrenheit marks a quite indefinite point, being thirty-two divisions on that scale below the freezing point, and is generally supposed to indicate the degree of cold obtained by mixing snow and salt. A temperature of —6.5° F. can, however, be thus produced.

The standard of 32° Fahrenheit is the temperature of pure melting ice; and of 212° that of steam from pure water boiling under a pressure of (760 mm.) 29.922 inches of mercury.

The small size of its degrees and the comparative freedom of its readings from minus signs are the decided advantages of the Fahrenheit scale.

SELF-REGISTERING THERMOMETERS.

The highest and lowest air temperatures occur at irregular hours and continue but a brief time, and to insure

(45° of latitude), these two readings would be respectively 29.923 and 29.932 inches.

a record of these important phases of heat special instruments have been devised.

The most important of self-registering thermometers is the minimum, since the lowest temperature usually occurs at night, slightly before dawn, and so is less likely to be observed. Six, in 1781, devised the first self-registering thermometer, which recorded both the maximum and minimum temperatures. The action of Six's instrument (which is U-shaped) depends on the expansion of a considerable quantity of alcohol in one arm which displaces a U-shaped column of mercury when the temperature rises, while the contracting spirit during falling temperature permits the pressure of air in the top of the other arm to cause a movement of the mercury in the reverse direction. The moving column of mercury displaces movable indices, which thus indicate the highest and lowest temperatures. The instrument is used now somewhat in Great Britain, and more rarely in the United States, since its indications are not strictly accurate, and it easily gets out of order in transportation.

The minimum thermometer of the pattern devised by Rutherford is to-day the accepted standard, and is in very general use. In this thermometer there is immersed in the spirits of wine a small steel index, the simple weight of which is so slight that the liquid, contracting in the tube, does not separate and leave dry the index, but drags it back, its upper end remaining tangent to the end of the receding column of alcohol. When the temperature rises, the expanding fluid passes freely by the index, and its upper end remains at the point of lowest temperature. The thermometer is set by raising the bulb slightly so that the index may move gently to the top of the column.

This thermometer, in common with all spirit thermometers, is subject to serious errors, owing to the upper part of the spirit column evaporating and rising to the top of the tube, where it condenses and remains detached. This separation of the column frequently occurs, and while the detached part measures ordinarily but one or two, yet its value occasionally amounts to ten or even fifteen degrees. Observers should not only carefully and daily examine the spirit thermometers to guard against this error, but should regularly compare the current readings with mercurial instruments, since the colorless character of spirits of wine renders detection of detached parts somewhat difficult. The writer was once called upon by an intelligent observer to examine his minimum thermometer (a standard instrument), which, he complained, always read lower than the Signal Service instrument near by, and to explain the cause of discrepancy. The observer was much chagrined when a detached section of spirit, equal to three or four degrees upon the scale, was pointed out to him at the top of the tube. It would be a decided check to this source of error if a marked coloring matter could be introduced as a permanent and unchanging part of the spirits of wine, but unfortunately the red coloring matter, occasionally used, separates from the fluid, thus introducing another source of error.

Whenever the column of spirit is broken into detached portions, or the index has been forced out of the fluid, the thermometer can generally be restored to good condition by swinging it quickly, but steadily, bulb downward, until the entire column unites. When this course fails, the detached bits of spirit are sometimes united by tapping the instrument quite sharply on the hand or some other elastic body. As a final resort the thermometer may be immersed in water which should be very gradually heated until the spirit completely unites. The two latter methods should be resorted to only in extreme cases, and the last process followed with great caution, lest the instrument break from the expansion of the alcohol.

Minimum thermometers with cylindrical bulbs are generally recommended; spherical bulbs take the temperature of the air too slowly, owing to the comparatively small exposed surface, while bulbs of such shape as to present to the air very large surfaces, and thus enhance the instrument's sensibility, are generally so fragile as to be out of place, except in the hands of the most skilled observers.

One source of error in the reading of the Rutherford minimum is the displacement of the index by high winds or other disturbing causes. This source of error is guarded against in Baudin's vertical minimum thermometer, *à marteau.** This thermometer is placed, like an ordinary instrument, in a vertical position. The index terminates at each end in spherical glass balls. A delicate spring with one end free is attached to the index, and is so arranged that its pressure against the tube keeps the index in a fixed position. The spring, however, is not so strong as to prevent the film of the contracting column of alcohol from drawing the index downward when the temperature falls. The thermometer is set by turning it bulb upward when a light enamel rod in the bulb of the thermometer descends the bore and, acting as a hammer, forces the index to the end of the column of alcohol. This thermometer is highly recommended.

There are several devices for registering the highest

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* The name of the thermometer *à marteau* refers to the rod used in setting it.

temperature attained by the air. In Rutherford's maximum the expanding mercury pushes before it a light porcelain index, which remains at the highest point until it is reset by placing the instrument upright and allowing the index to drop to the mercury. This instrument is not much used.

The Phillips maximum has a bubble of air introduced into the column, about an inch from the upper end, which is thus detached. When the mercury contracts the detached end remains fixed, and thus, serving as an index, marks the highest temperature. This instrument is falling into disuse, since the air bubble is readily displaced, either by rough handling during transportation or by the mercury being withdrawn into the bulb by lower temperatures than the instrument registers.

The maximum thermometer most in use is somewhat after the pattern devised by Negretti and Zambra. Just above the bulb there is a slight constriction in the tube through which the expanding mercury is forced, but which causes the column to break when the mercury begins to contract. The column remains at the highest point until the thermometer is set by detaching the suspension pin and whirling the thermometer around the pin, which passes through its upper end.

The Richard self-registering thermometer, shown in Fig. 4, has many parts similar to the self-registering aneroid. The essential or thermometric part is the copper bulb, A, filled with alcohol.

As the temperature fluctuates, increasing or diminishing the volume of alcohol, the curvature of this crescent-shaped bulb changes. The motion of the free end is transmitted by a compound lever to the marking pen. When the instrument is set up or the sheet renewed, once a week, the pen should be made to register the same as the dry thermometer. This adjustment is made by means of the nut at *c*, turning it so as to raise or lower the pen.

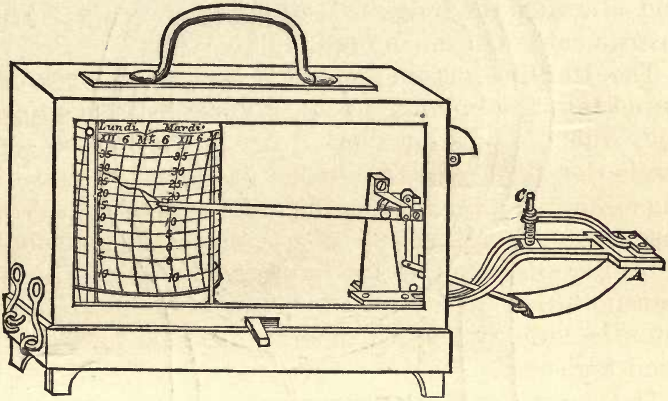


FIG. 4.—RICHARD'S REGISTERING THERMOMETER.

The Draper self-registering thermometer is a metallic instrument, wherein strips of steel and brass (see Fig. 5) about 12 inches long are soldered together. The difference in their expansion causes changes in the curvature of the strip, one end of which is fixed. The movements of the other end, by a simple device, produce the motion of a registering pen. There are two of these compound strips, so arranged as to curve in opposite directions as the temperature changes. They act on opposite sides of the pivot of the marking pen, in order to insure greater accuracy in the record when the temperature is fluctuating.

The record being traced on a disk, the fluctuations for a whole week can be seen at once. The disk holding the record paper is made to revolve by clockwork once a week. The indications of the instrument are generally trustworthy to within two degrees F.

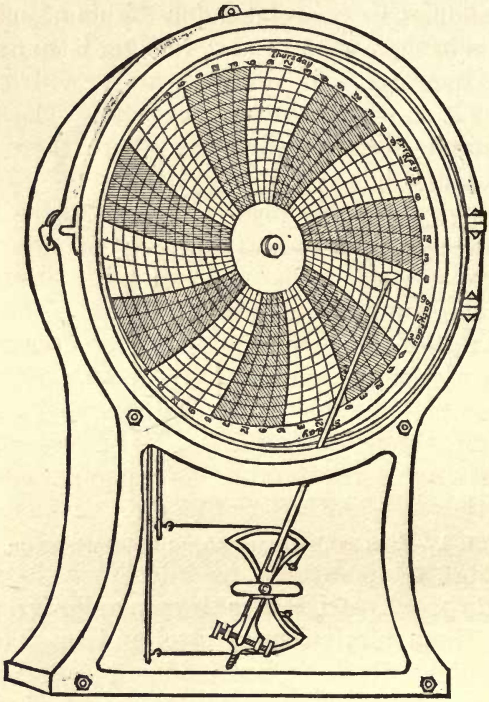


Fig. 5.—Draper's Registering Thermometer.

THERMOMETER EXPOSURE.

The question of the immediate environment of the thermometer is a most important consideration. Full and free natural ventilation is essential, and rain should be excluded. Provision should be made against heat from direct solar radiation or that reflected and radiated from surrounding objects, especially from warm walls, chimneys, etc.

While a fixed instrument shelter is convenient, and for self-registering instruments indispensable, yet most accurate single temperature readings, both of dry and wet thermometers, are obtainable by another method. It consists in the use of dry and wet bulb thermometers fastened together and quite rapidly whirled by a string, held in the hand or otherwise. The observer should stand in an open space where there is good ventilation and be shaded from the sun.

The rapidly varying heat phases of the air, consequent on convection, radiation, and reflection, make it difficult to so place a thermometer as to insure its indicating the true temperature of the air. The pattern and material of the shelter, with its freedom from surrounding objects, which unduly reflect or radiate heat, as well as the height of the thermometer above the ground, are conditions which more or less materially affect the correct reading of thermometers used to determine the temperature of the air. It was once the experience of the writer in investigating the cause of unduly high temperatures, recorded by a thermometer apparently well placed in a standard louvre shelter, that the disturbing element was a painted tin roof, some fifty feet distant. This roof, reflecting the sun's heat at an obtuse angle, raised the temperature at times from two to three degrees.

A thermometer shelter should have double roofs six or eight inches apart, a solid bottom, which should be hinged, so it can be closed or not, and sides of blind or louvre work. The slats of the sides should slope at an angle of 45° and be quite close together. When practicable, the shelter should be from eight to ten feet above the sod or the roof, in the latter case having a large wooden platform beneath it. When a window shelter is necessary, it should be on the north side, and as open as possible, care being taken to barely protect the thermometer from the effects of the sun and from rain. Openness of shelter thus tends to counteract

Station Thermometer.

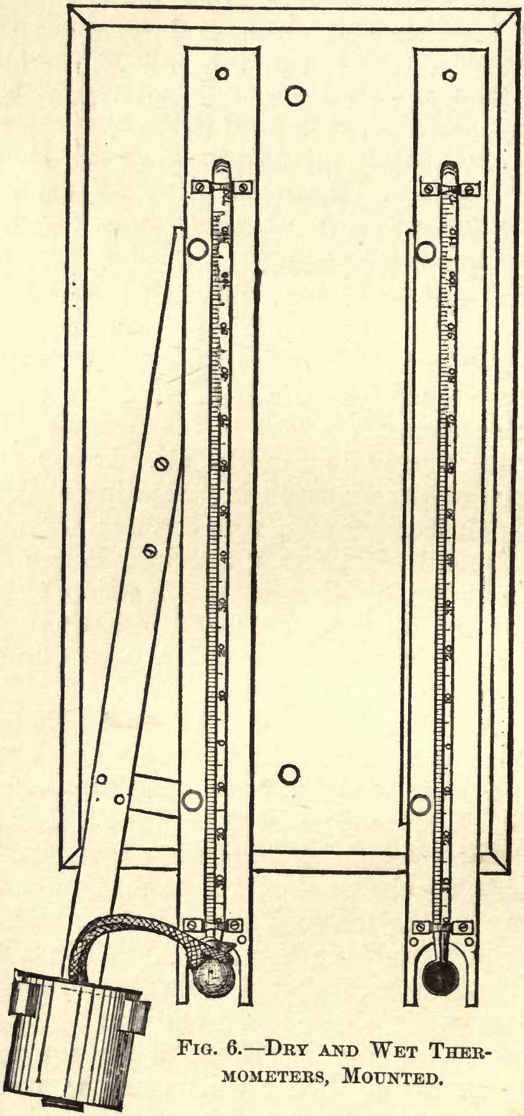


FIG. 6.—DRY AND WET THERMOMETERS, MOUNTED.

the effect of the temperature of the wall, which is too cool by day and too warm at night.

The wet thermometer is only a dry bulb covered with soft muslin well wet with rain or clear water, drawn from an attached cup or cistern by a wick. The muslin should be kept in good order, always clean, so that the water will be fully drawn from the cistern and the bulb kept wet. Readings below 32° require care and watchfulness, since the bulb must be skilfully covered with a thin coating of ice and well ventilated, so that evaporation may take place normally and speedily.

The arrangement and relative position of dry and wet thermometers is shown by Fig. 6.

Artificial ventilation, unnecessary if there is wind, becomes quite an important adjunct in calm weather. It is, perhaps, best obtained by rotating the thermometer by a whirling apparatus, fan or bellows worked by some simple mechanical device; but when these are not convenient a fan moved by hand will answer the purpose. It may be added that this is the most difficult meteorological observation to make satisfactorily, and that trivial defects or slightly inaccurate readings destroy completely its usefulness. It is, however, a most important observation for agriculturists, especially at the time of early or late frosts.

Maximum and minimum thermometers are often conveniently mounted together on a small base board (see Fig. No. 7), which is easily fastened in the instrument shelter or other suitable place. The minimum should be mounted nearly horizontal and the maximum with its bulb slightly inclined downward. The minimum is set by lifting up the bulb till the index drops to the end of the alcohol column. In setting the maximum, remove the pin, thus allowing the

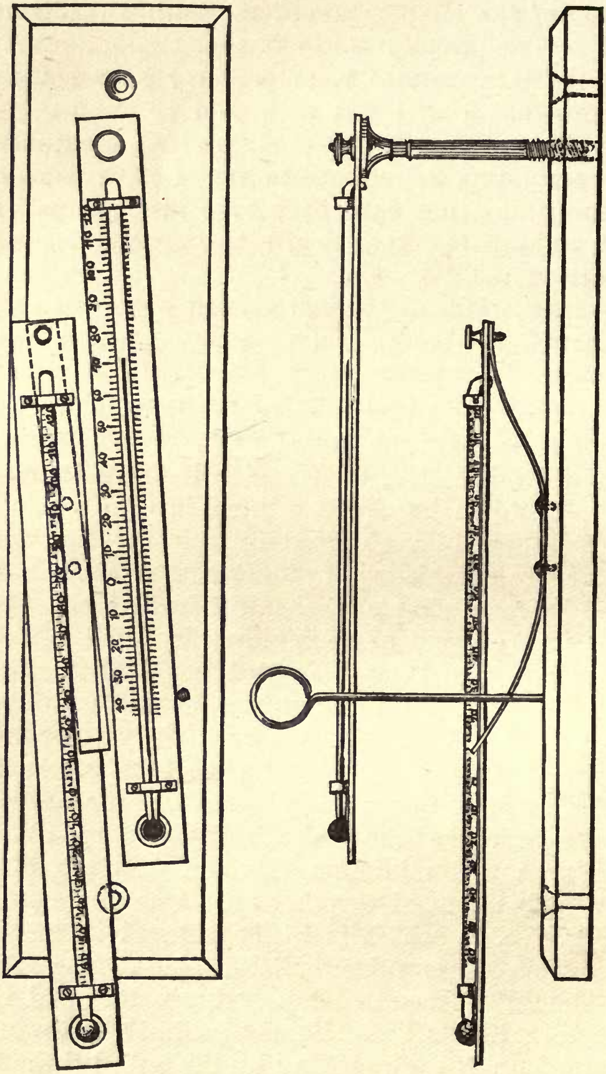


FIG. 7.—MAXIMUM AND MINIMUM THERMOMETERS, MOUNTED.

thermometer to drop in a vertical position. The mercurial column usually unites at a single tap, but if it does not the instrument must be revolved rapidly on the screw that secures it to the board.

The observations made from standard instruments in properly exposed situations are of little practical or theoretical value until they have been grouped, reduced, and collated, so as to give means or averages for comparison and discussion.

The fluctuations of the temperature of the air are so continuous, and occasionally so rapid and marked, that even observations every ten or fifteen minutes would not give an absolutely correct mean of the day.

The average of twenty-four observations, taken at hourly intervals, is, however, by common consent, assumed to be the true mean temperature of a day. To obviate the necessity of taking even so many observations, other methods have been elaborated, by which comparatively correct daily means are obtained. These methods are: First. From readings of maximum and minimum self-registering thermometers, a mode entailing little labor. Half of the sum of these two readings gives a mean slightly inaccurate—it generally being a little higher, less than a degree above the true mean. Corrections necessary to approximately reduce this to the true mean have been calculated for the various months and different parts of the United States, which are given in Table No. 4.

Second. From observations at a selected hour. At New Haven, Conn., for instance, according to Loomis, the temperature at 8.45 A.M. or 7.45 P.M. coincides with the mean temperature of the day. This critical hour varies not only in localities, but also for the month. It can be determined only from a long series of observations, and so cannot be generally adopted.

Third. From observations at any two hours of the same name. While the mean of such similar hours, as 9 A.M. and 9 P.M., differs but slightly from the true mean, yet it requires a series of observations to select hours when the error is but a few tenths of a degree. At New Haven the daily mean thus deduced from observations at 10 A.M. and 10 P.M. is only about one third of a degree too low.

Fourth. From three daily observations at equal or nearly equal intervals. The average of any three such hours varies but little from the true mean of the day. It has been found, however, that the most satisfactory method for all varieties of climate is obtained from observations at 7 A.M., 2 P.M., and 9 P.M. While the mean of these observations is a little too great, this error is substantially eliminated by adding the 9 o'clock observation twice to the other observations, and dividing the sum by four. This method is strongly recommended to observers.

The monthly mean is obtained from the daily means. The annual mean temperature is usually found by taking the average of all the monthly temperatures for the year; but this process causes a slight error, by giving equal weight to months of unequal length. For very exact work, the preferable way is to obtain the annual mean directly from the daily averages of the whole year. The annual mean varies from year to year, and the mean temperature of a place is the average obtained from a series of years—twenty or more.

CHAPTER IV.

RADIATION.

Before proceeding to treat the subject of aqueous vapor, it will be advisable to touch on radiation, through the action of which such great changes are wrought in the temperature of the air and in the condition of aqueous vapor itself.

Radiation is the propagation of heat from a warm body through space. The transmission takes place in straight lines. The radiation from the earth is called terrestrial radiation ; that from the sun solar radiation. The temperature at the earth's surface depends entirely on these two processes. The amount of heat coming to the surface of the earth from the interior or that received from other stellar bodies than the sun is not enough to appreciably affect our climate.

Our knowledge of the amount of heat received by the earth from the sun is, as yet, very uncertain, the instrumental means so far devised for ascertaining it being very imperfect and giving widely varying results.

The actinometers of Herschel, Pouillet, Stewart, and Violle for measuring the amount of solar radiation are alike in principle, that the heat received from the sun plus that lost by radiation is the true amount. The thermometer is surrounded by material tending to preserve an equable temperature. The instrument is exposed a given time to the sun, and its increment of temperature noted, and later, after being placed an equal time in the open shade, the loss of heat is noted. Pouillet used water around the thermometer, Stewart cast iron, and Violle ice, the last being doubtless the best. These instruments are complicated and their use difficult. For a detailed description, the reader is referred to works on physics.

The quantity of heat that will raise one gramme of water at a temperature of zero degrees centigrade, one centigrade degree is called a calorie.

A surface of one centimetre square exposed perpendicularly to the sun's rays at the top of the atmosphere would receive in one minute of time 3.0 calories (Langley). This is the best value for this quantity, so far as ascertained. It is called the solar constant. The value found by Pouillet was 1.75.

This amount is sufficient in a year to melt a layer of ice 178.6 feet (54.45 metres) in thickness. A great deal of this heat is absorbed by the atmosphere before it reaches the earth, according to Langley, $\frac{1}{3}$ of the amount when the sun is in the zenith, and according to Pouillet, $\frac{1}{4}$ or $\frac{1}{5}$. For other positions of the sun than the zenith, a greater part is absorbed, as the rays traverse a greater thickness of the air before reaching the earth's surface. Without this power of the air to absorb the heat, called selective absorption, the temperature at the earth's surface would eventually, according to Langley, not be greater than −328° (−200° C.).

The amount of heat that is absorbed at different times varies greatly, depending on the quantity of particles in suspension and the amount of aqueous vapor in the air.

The bright and black bulb thermometers *in vacuo* afford a ready means of measuring relatively the amount of this heat that is absorbed at different times. The less the quantity of heat absorbed by the air, the higher will be the reading of the black bulb thermometer as compared with the bright bulb. But this affords by no means an accurate measure, as the black bulb readings vary for other reasons, the most important of which are the thickness of the lamp-black with which it is covered, the size of the bulb, the thickness and chemical nature of the glass composing the enclosure, and the imperfection of the vacuum.

The selection of a pair of bright and black bulbs for standards, with which the errors of other solar thermometers are determined, affords in some measure the method of obtaining quite accurate indications of the relative amounts of heat absorbed by the air at different times and places. These thermometers are usually made maximum registering, and it is customary to take as their indications the differences of their greatest readings for the day. When the sun is low the differences will not be as great as when the sun is higher, as in the former case the rays traverse a greater thickness of air and more of the heat is absorbed before reaching the bulb.

But the relation between the thermometer differences and the heat absorbed is not a simple one. A slightly less amount of heat absorbed by the air will cause a very considerable increase in the differences. As one ascends in the air above the level of the sea the reading of the black bulb *in vacuo* increases extraordinarily when exposed to the sun.

Comparatively few observations of this character have been made in the United States, but there is every reason to believe that observations from such instruments in certain parts of Arizona and the arid regions of the West would show temperatures ranging, in extreme cases, from 160° to 180°, if not higher. It is evident that at elevated stations in dry districts of the earth the direct effect of the sun's rays is, proportionately, very much higher than the true temperature of the air, as compared with localities near the sea or in more humid regions.

At Leh, Ladak, Thibet (elevation, 11,500 feet), the air is so clear and transparent that, according to Dr. Cayley, "by simply exposing water in an ordinary phial, inked on the outside, and placed within a larger bottle, the contents boiled under the action of the sun's rays." The temperature at which water boils at Leh, owing to the diminished atmospheric pressure, is about 190°. Scott is the authority for saying that at this station solar thermometers have registered 214°, or higher, but 158.4°, in 1875, is the highest temperature which Blanford gives in eight years. It is probable that the temperature of 214° at Leh must have been from a thermometer under some such conditions as the water exposed by Dr. Cayley.

Langley's experiments on Mount Whitney show that very much higher temperatures are indicated by thermometers carefully protected from loss of heat than by black bulb *in vacuo*. On September 19th, 1881, Langley obtained from a sun-thermometer (black bulb), thus protected, a temperature of 236°, while the highest reading of the black bulb *in vacuo* was 170°.

The highest temperature from such instruments under ordinary exposure, as far as the writer has been able to gather from original sources, is that reported by Blanford—196.5°—which was recorded on June 8th, 1882, at Pachpadra, India, elevation, 380 feet. A few other cases of temperature above 190° are found in Blanford's reports, and these temperatures have been corrected with reference to a thermometer adopted as a standard by the meteorological reporter of the Government of India. The mean excess of maxima temperatures in the sun above those in the shade at Bickaneer, India, 28° N., 73° E., elevation, 744 feet, equals 69.8° for the year and 74.0° for February.

At Fort Conger, 82° N., 65° W., the maximum black bulb averaged for thirty consecutive days, from April 13th to May 12th, 1883, 75.4° above the shaded thermometer. As long as the ground remained frozen and the sea ice was unbroken, the solar radiation steadily increased, and the instant these conditions changed a decrease began. Differences of 80° or more between the maximum black-bulb and shade thermometer were not infrequent at Fort Conger, and on May 5th, 1883, the extraordinary difference of 95.9° was observed. On May 31st, 1883, a maximum reading of 124.5° was noted—this reading being almost coincident with the highest reading the same year at Point Barrow, Alaska, and Jan-Mayen Island—127° and 120.8°, respectively. The highest reading ever noted at Fort Conger—128°, June 6th, 1876—was five days before snow had melted so that water ran freely.

The small amount of aqueous vapor in the winter air of the polar regions or on elevated plateaus and mountains permits the direct rays of the sun to exercise a powerful influence on surfaces of high absorbing powers. Parry, at Igloolik in February, 1822, noted snow melting on a black surface with the temperature of the air at −19°. The story of melting pitch observed by whalers, while ice was forming in the shade, is more striking, though really less remarkable.

A simple reliable method of measuring the sun's heat throughout the day is especially desirable, and the invention of a suitable instrument would be an important contribution to meteorology.

But if the amount of solar radiation cannot be conveniently and accurately measured, there is a simple method of estimating the effect by observing the duration of sunshine.

The Campbell-Stokes sunshine-recorder is a simple, inexpensive instrument, which records sunshine quite accurately. A glass sphere acts as a lens, with its focus on a curved strip of mill-board, ruled for the hours, which is burned as long as the sun shines. Professor Marvin, United States Signal Service, has devised a photographic method of registering, whereby a record for a month is obtained on a single sheet.

The effect of solar radiation naturally varies with the absorptive powers of the surface on which the sun's rays fall, being greatest on substances such as lamp-black, paper, etc., and least on polished metals. Since sandy soils have large absorptive powers, it is evident why sandy desert regions attain such extreme temperatures, and since so much heat is used in evaporating from surfaces of water and ice, lakes and the ocean have comparatively low temperatures as a greater mass is warmed, the heat penetrating the water to some depth, about five hundred feet.

Since the radiating power of differing surfaces is not uniform, it follows that observations are not comparable unless the conditions are identical. As yet there has been no agreement between the various meteorological services on this point, and indeed but scanty attention has been paid to the subject, nor have continuous and extended observations been made except in India.

The most important observations on solar radiation ever made in the United States, and probably in the world, were those of Professor Langley, on Mount Whitney, California.*

* (See Professional Papers, No. 15, Signal Service, "Researches on Solar Heat," by S. P. Langley.)

The result of Langley's observations was to show:

1. The value of the solar constant was far larger than had been supposed.

2. That the amount of heat absorbed by the air was likewise much greater than had been previously estimated, and that this latter absorption was of a selective character, and,

3. In particular that the absorption of the air diminishes progressively as the wave length increases, up to a certain very long wave length—that is to say, that up to a certain estimated limit the air becomes more and more transparent, to the reddish rays and to the invisible ones of heat. This latter is the very reverse of the opinion entertained prior to his work.

4. He also showed that of two like masses of air selected first at a high elevation, and second at a low, the former absorbs the less heat—that is to say, that the upper air absorbs less heat quite independently of its rarity.

5. By means of his sensitive measuring device called the bolometer, he discovered that solar heat waves of at least 0.003 of a millimetre (probably more) were transmitted by the air, a little over 0.001 being the longest heat wave that had been before detected under the circumstances.

Terrestrial radiation, or escape of heat into space, is a constant phenomena, which plays a very important part in climatic changes, especially in the United States, as will appear from the chapter on "Cold Waves."

Repeated and careful experiments have conclusively shown that radiation proceeds at its maximum rate to the clear sky. It is further intensified by the absence of aqueous vapor from the air, and is diminished whenever clouds or any intervening object cuts off the clear heavens.

Terrestrial radiation is commonly measured by a minimum thermometer, usually black bulb, which is exposed at the height of the grass, on green sward. Clay, gravel, or earth are poor radiators, while grass and kindred vegetation radiate heat much more rapidly. The lamp-black, covering the thermometer bulb, is used, owing to its having the greatest radiating power of any known substance.

The only extensive and regular set of observations on nocturnal radiation are those which have been carried on for a number of years in India. As a general rule, the greatest difference between the temperature of an ordinary minimum thermometer and of the black bulb occur in the winter months, when average differences of from 12° to 15° are not unusual. The greatest average monthly difference in India is 19°, at Chikalda, in December; the greatest difference, for a single observation, was noted at Simla, 31°, in December, 1884.

An equally great difference between the minimum black bulb and the shade minimum was observed at Fort Conger, 31°, December 28th, 1882. The maximum difference was 25° at both Point Barrow and Fort Rea in 1882–83. This difference depends largely on the stillness of the air, being greatest when it is perfectly calm.

An accurate knowledge of the conditions under which extreme radiation occurs and the extent to which it lowers the temperature of vegetation or other substances is not alone of interest, but is practically of importance. Experienced gardeners partly avoid the effects of late and early frosts by planting tender vegetation on hill-slopes and not in low-lying lands, and, when clear, calm nights follow dry winds by day, guard against radiation and protect their plants by light covering of straw, etc.

In Northern India, where water under ordinary conditions never freezes, advantage was taken of the operation of Nature's laws to obtain a supply of ice by facilitating radiation and evaporation.

John Eliot, Esq., the meteorological reporter to the Government of India, kindly furnishes to the author the following account of the methods followed in India:

"This method was formerly practised at all the large stations in the interior of Northern India (*e.g.*, Umballa, Lahore, Meerut, Agra, Cawnpore, Allahabad, Benares, Patria, and as far east, I believe, as Hooghly).

"At Roorkee, where I was first stationed, the following was the method: The place selected was open and away from trees. It was in one of the lowest parts of the station, with rising ground in all directions from it; shallow, unclosed porous burnt-clay dishes were used of elliptical form, and were placed on a thick bed of straw to isolate them from the ground as far as possible.

"The period during which ice could be made in this way lasted from November to February. During this period perhaps one night out of three would be favorable. Ice could only be made on perfectly clear, calm nights. The thinnest veil of cloud or air motion of winds was fatal to success.

"The most favorable nights were those which succeeded stormy, snowy weather in the Himalayas, when the air in Northern India is for a few days unusually cool and dry and remarkably clear and free from cloud, dust, etc.

"When the weather was judged to be favorable, some thousands of these shallow dishes were nearly filled with water during the afternoon. Usually (*i.e.*, if conditions continued favorable) the water was found to be converted into ice next morning.

"The cause of the formation of ice was undoubtedly the rapid radiation which takes place in clear, still nights, during the cold weather in Northern India.

"This effect was increased, 1st: By the use of porous vessels. The outside surface evaporation, due to slow percolation of water through the sides of the vessels, subtracted heat from the water in the vessels. 2d: By placing the vessels on straw, thus preventing any flow of heat from the earth to the vessels."

CHAPTER V.

HUMIDITY AND EVAPORATION

Not only is aqueous vapor an abundant element of the atmosphere, but it is meteorologically most important, whether in gaseous, liquid, or solid form. Notwithstanding the great stress and weight meteorologists place, and properly so, it is believed, on the intricate relation of aqueous vapor to the development, progress, and intensity of storms, yet it is practically the least accurately determined and most unsatisfactorily recorded of all weather elements.

As has been stated, air acts according to a certain law in altering its volume under changes of pressure and temperature, but when vapor laden there are certain limits to the gaseous state. A cubic foot of air, for instance, can only contain aqueous vapor in varying quantities, dependent almost entirely on temperature. When the limit is reached the air is said to be *saturated*, and if the temperature is lowered it follows that some of the aqueous vapor will be condensed and pass into a liquid form, as dew or rain, or solid form, as snow, hoar-frost, etc.

Before this limit is reached the air will absorb moisture from water or other damper surfaces than itself, as from snow, ice, etc., through the process of evaporation, whereby the snow or water passes rapidly and most often invisibly from a solid or liquid to the gaseous state. Conversely, by the process of condensation, owing to the lowering of the temperature, the aqueous vapor changes rapidly from its gaseous condition to a liquid or solid state.

Since a large quantity of heat (the latent heat of evaporation) is required to change the solid or liquid form of water into the gaseous condition of aqueous vapor, it follows that evaporation lowers the temperature of surrounding bodies from which the heat, necessary for the process, is drawn. It is through the effect of evaporation that perspiring persons are cooled by fanning themselves or sitting in a draught of air, and by similar action water in tropical or semi-tropical regions is kept cool either by the evaporation from the exterior surfaces of porous vessels or from wet cloth coverings. The loss of heat thereby from any given surface is directly proportional to the absolute quantity of water evaporated from it.

High temperature and strong winds favor evaporation greatly, since at high temperatures not only will the air contain more vapor, but the water passes more quickly into the gaseous stage; and the greater the quantity of air comparatively free from vapor passing over the water surface, so much the more is evaporation facilitated. Evaporometers (or atmometers) in general use are of two classes, the first of which determines the evaporation by the use of a balance, whereby the loss of weight is measured. This class is indispensable in satisfactorily determining evaporation from earth, soils, etc., in agricultural experiments. The second class measures the changes of level in free water surfaces, the pipe in which the measurements are made being often much smaller than the exposed pan from which it is fed, so that even slight evaporation is quite accurately measured.

Mitchell's and Von Lamont's are evaporometers of the second class, which, however, is giving way to a third form, wherein the evaporation is not from a free surface of water, but from a moistened porous bulb or paper disk, which allows water to slowly escape from a glass tube.

The Piche evaporometer, Fig. 8, consists of clean or distilled water in a glass tube, nine inches in length, which is graduated to show the contents in cubic centimetres and in tenths. Evaporation takes place from the surface of a paper disk, which is kept in place at the lower open end of the tube by a brass spring attached to a slitted collar that moves along the tube. Evaporation is about twice that from an equal surface of free water, as shown by the observations of Foerster and Riegler, but the rate varies with different exposed areas, and must be determined for each class of instruments. These evaporometers are used at special stations of the Signal Service, in order to ascertain the relation between the amount of evaporation and the mean daily temperature and dew-point, and the wind velocity. The instrument is suspended in the shade, and the tube is refilled as often as is necessary, the paper disks being renewed at the same time. The instrument cannot be used in temperatures below 32°.

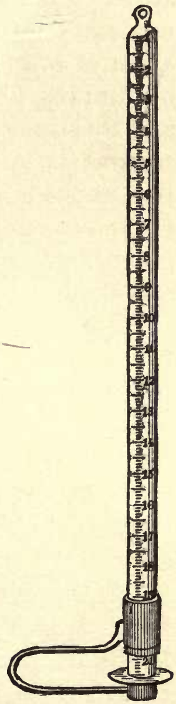


FIG. 8.—PICHE EVAPOROMETER.

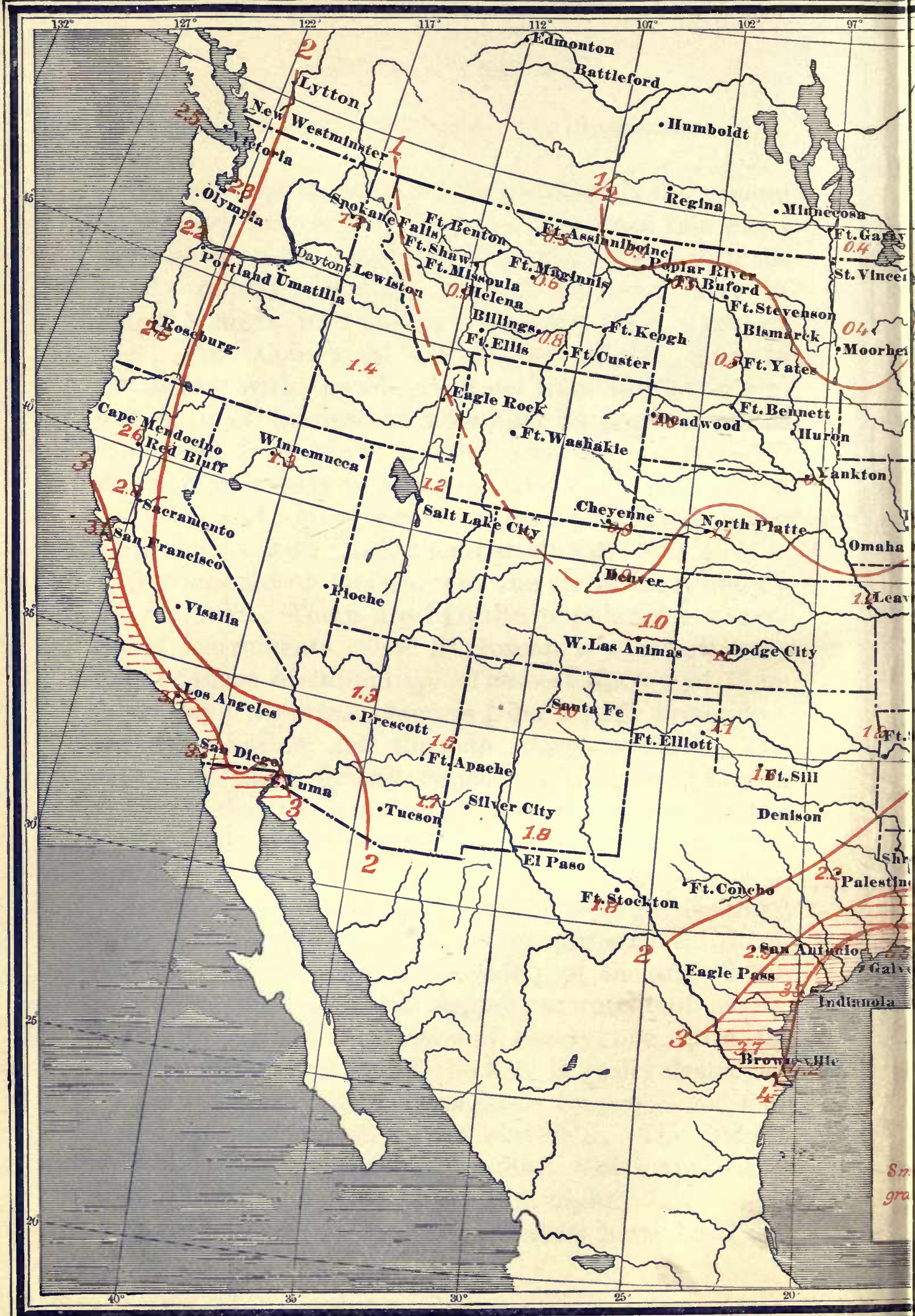
Observations on evaporation have been quite unsatisfactory, owing to the rate varying with dissimilar surfaces, whether of shape or substance; to the fact that the vapor diffuses itself irregularly, and because methods of exposure and measurement have not been such as to make the observations comparable.

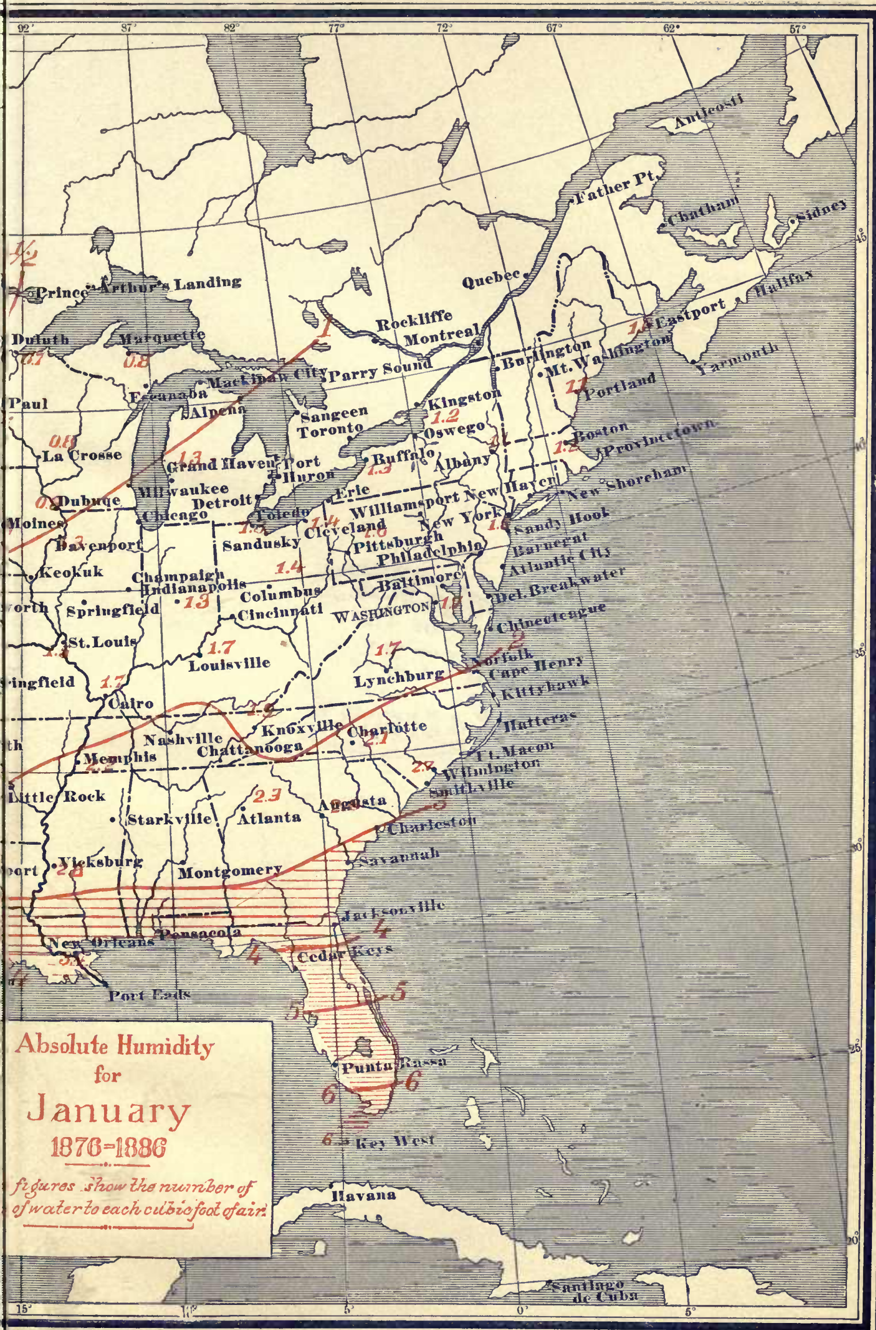
The outcome of scattered observations is the general expression that the annual evaporation from free water surfaces near the ocean substantially agrees with the yearly rainfall. Among amount recorded may be noted Madras, 92.2 inches; Nagpur, 73.2; London, 20.6; Fort Conger, 81° 44′ N., 64° 45′ W., 8.9. In connection with the observations from the latter station, it is of interest to note that its evaporation, as calculated from eight months' observations, exceeded the rainfall nearly five inches; also that evaporation from ice and snow ceased for a period of four and a half months, with a mean temperature of — 31°.

The amount of moisture in the air is measured by hygrometers. There are in quite popular use a number of instruments called hygroscopes, which indicate only changes of humidity. The best known of these is the toy; a woman emerges from a little house during dry weather, and the man in wet weather. The action of these figures depends on the well-known principle that the length of catgut, whalebone, or the human hair varies largely through change of moisture.

Saussure and others have demonstrated the accuracy with which a human hair, under proper conditions, will indicate the relative humidity of the air. Some hair before breaking will support a weight of nearly four ounces, and will stretch nearly one third its length. The elasticity of the hair is easily destroyed by the slightest excess of weight or by protracted tension near its limit of perfect elasticity. The weight should not exceed one half gramme, which applied to a thoroughly damp hair keeps it straight.

Many patterns of hair hygrometers have been de-


132°
127°
122°
117°
112°
107°
102°
97°
Edmonton
Battleford
Humboldt
Lytton
New Westminster
Victoria
Olympia
Regina
Minnecosa
Ft. Garry
St. Vincent
Spokane Falls
Ft. Benton
Ft. Assinniboine
Poplar River
Ft. Buford
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Helena
Dayton
Lewiston
Portland
Umatilla
Ft. Stevenson
Bismarck
Billings
Ft. Keogh
Ft. Ellis
Ft. Custer
Ft. Yates
Moorhead
Roseburg
Eagle Rock
Deadwood
Ft. Bennett
Huron
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Yankton
Sacramento
San Francisco
Salt Lake City
Cheyenne
North Platte
Omaha
Pioche
Denver
Visalia
W. Las Animas
Dodge City
Los Angeles
Prescott
Santa Fe
San Diego
Ft. Apache
Ft. Elliott
Ft. Sill
Yuma
Tucson
Silver City
Denison
El Paso
Palestine
Ft. Concho
Ft. Stockton
San Antonio
Eagle Pass
Indianola
Brownsville
45
40
35
30
25
20
40°
35°
30°
25°
20°


Absolute Humidity
for
January
1876-1886
figures show the number of
of water to each cubic foot of air.
Anticosti
Father Pt.
Chatham
Sidney
Halifax
Quebec
Prince Arthur's Landing
Duluth
Marquette
Rockliffe
Montreal
Eastport
Yarmouth
Burlington
Mt. Washington
Portland
Parry Sound
Mackinaw City
Escanaba
Alpena
Kingston
Sangeen
Toronto
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
New Haven
New Shoreham
Milwaukee
Detroit
Erie
Dubuque
Chicago
Toledo
Williamsport
New York
Sandy Hook
Moines
Davenport
Sandusky
Cleveland
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Lynchburg
Norfolk
Cape Henry
Kittyhawk
Cairo
Knoxville
Charlotte
Hatteras
Nashville
Chattanooga
Ft. Macon
Memphis
Wilmington
Smithville
Little Rock
Augusta
Starkville
Atlanta
Charleston
Vicksburg
Savannah
Montgomery
Jacksonville
Pensacola
New Orleans
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba

vised, in order to obviate the well-known errors incident to observations of humidity deduced from readings of the dry and wet thermometers at temperatures below the melting point of ice.

The Koppe hair hygrometer is largely used in Europe, and while not perfect, is, perhaps, the best. The hair (see Fig. 9), fastened to a spring loaded with a half gramme weight, is wound around the axle of a dial needle. The adjustment, made by experiment or comparison, is such that in a wholly saturated atmosphere the needle stands at 100 on a scale graduated from 0, total dryness, to 100, complete saturation. The scale readings give the *relative* humidity in percentages, but the *absolute* humidity in grains of aqueous vapor to a cubic foot of air, or the dew-point of the air can be obtained by computation, for which an additional observation of the dry thermometer, suspended in the case, is necessary.

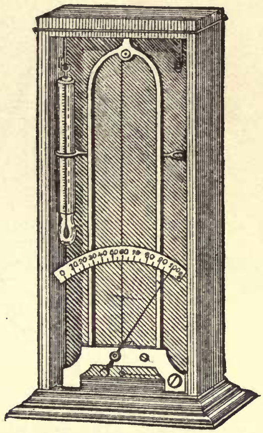


FIG. 9.—KOPPE'S HAIR HYGROMETER.

Professor Harkness has devised a convenient and reliable form, where the hair, suspended in a small metal tube, is weighted by one fifth of a gramme. A micrometer screw and scale permit the easy determination of the elongation of this hair. The values of the scale readings, which though arbitrary are constant under similar hygrometrical conditions, are determined by comparative simultaneous observations with Regnault's apparatus or from dry and wet thermometer readings. This instrument is compact, simple, and reliable ; it is worthy of careful test and examination.

The most accurate method of measuring the humidity is by direct hygrometers, such as Daniell's or Regnault's, which are constructed on the principle of condensation through evaporation.

Regnault's hygrometer, Fig. 10, consists of two cylinders, the lower ends of which, D D, are of highly

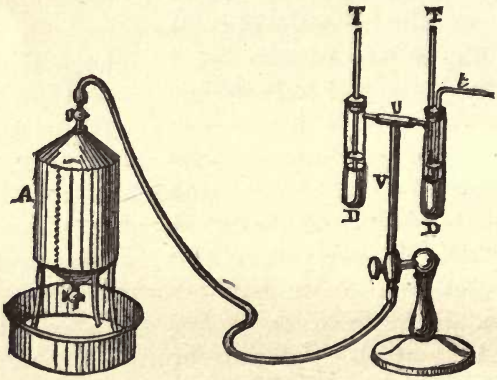


FIG. 10.—REGNAULT'S HYGROMETER.

polished silver, while the upper parts are of glass. Two thermometers, T T, inserted in the top, have their bulb near the silver bottom, one cylinder being empty and the other partly filled with ether, so as to cover the bulb of the thermometer. An aspirator, A, connected with the base of the hollow upright and cross-arms, V U, draws nearly equal quantities of air by each thermometer. One thermometer thus acquires the temperature of the external air. The other, chilled by cold from the evaporation of ether, caused by the air drawn through it from the tube *t*, falls to the dew-point, which is indicated by the appearance of a thin film of dew on the polished silver. The reading of this thermometer when dew forms gives the temperature of the dew-point. The apparatus and its manipulation are costly and inconvenient, so that the instrument is used only in important and accurate experiments, or in order to test or graduate the indications of other simpler and less expensive hygrometers.

The relative humidity is, however, obtained most commonly in the United States from simultaneous readings of the dry and wet thermometers, exposed side by side, as shown in Fig. 6. The cold of evaporation causes the wet bulb to read lower than the dry, unless, as rarely occurs, the air is completely saturated. The wet thermometer does not give the temperature of the dew-point, but it sinks to a point between it and the temperature of the air shown by the dry thermometer. The difference between the readings of the dry and wet thermometers bears a certain and quite constant ratio to the *complement* * of the dew-point, so that by an empirical formula the dew-point can be determined. In order to avoid the labor of calculation, tables have been elaborated, based usually on the factors formulated by Sir James Glashier, F.R.S., having been empirically obtained from the comparison of a very large number of simultaneous observations with Daniell's hygrometer and the dry and wet thermometers.

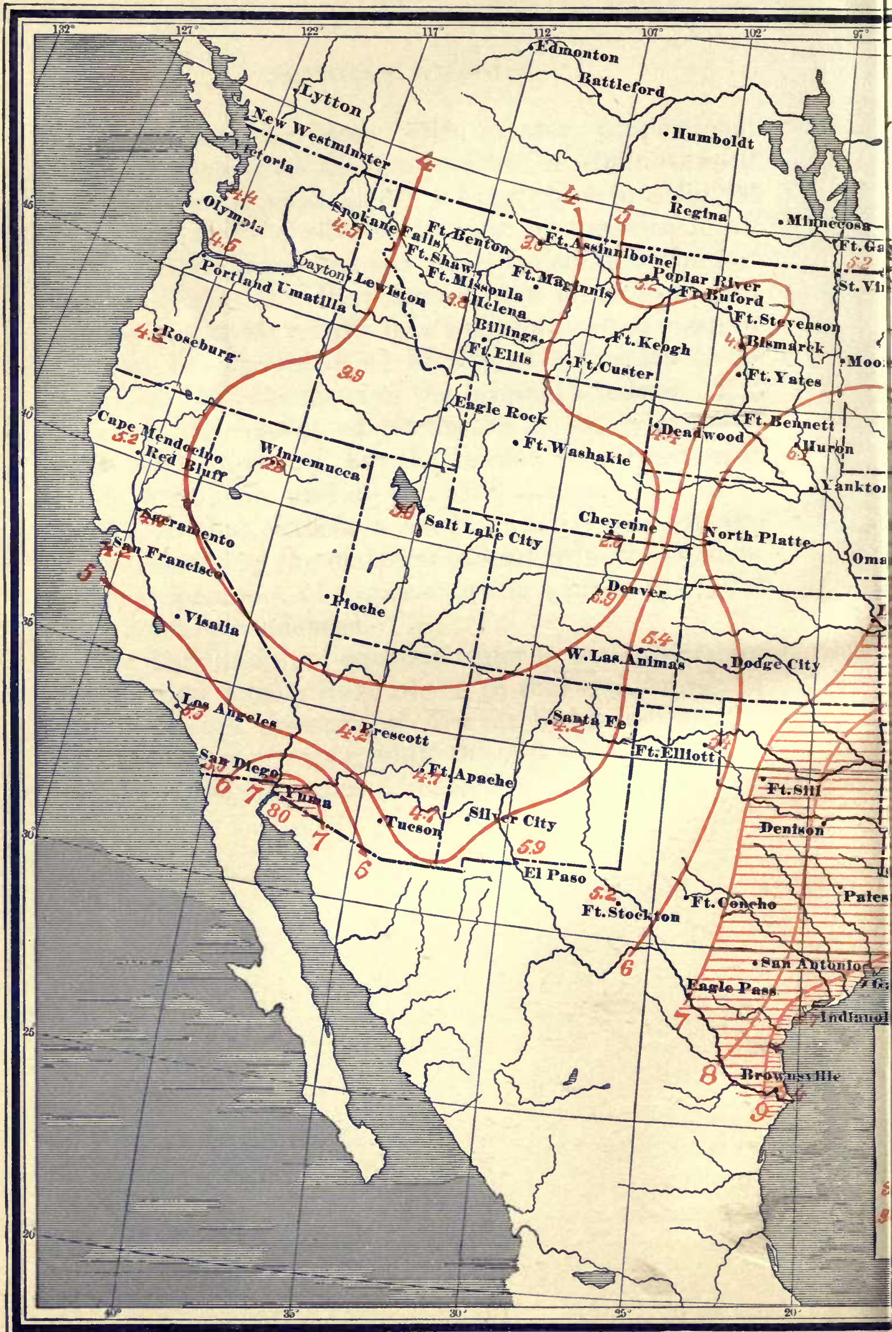
From these readings, then, can be obtained, first, the dew-point; second, the elastic force of vapor (that is, the amount of barometric pressure due to aqueous vapor present in the air); third, the quantity of vapor in each cubic foot of air. These values are to be found in Table No. 5.

An examination of the table shows that the tension

* This complement is the difference between the dew-point and the temperature of the air.

of saturation decreases with greater proportional rapidity than does the temperature, a diminution of one half the amount at 80° taking place in a fall of 21°, while at 20° a similar decrease occurs with a fall of 15°. This important fact tends to facilitate the formation of clouds. For instance, the mixing of equal masses of dry air results in a temperature the mean of the two, but the resulting tension of saturation is always less than the mean of the original tensions. For example, the tension of saturation at 70° is equal to .733 inch of mercury, but the tension of saturation at 80° is 1.023 inch, and at 60°, .518, the mean of which is .770, so that, except a small quantity kept in the gaseous state by the emission of heat from the condensation, an amount of vapor exerting a pressure of .037 inch must be condensed.

The distribution of aqueous vapor is but imperfectly known and locally determined, so that the process of obtaining the pressure of dry air by deducting the actual tension of vapor, while the best method, must be considered as only approximately correct.



Edmonton
Battleford
Humboldt
Lytton
New Westminster
Victoria
Olympia
Spokane Falls
Ft. Benton
Ft. Assinniboine
Regina
Minnecosa
Ft. Shaw
Ft. Missoula
Helena
Ft. Maginnis
Poplar River
Ft. Buford
Ft. Stevenson
Bismarck
Dayton
Lewiston
Portland
Umatilla
Roseburg
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Ft. Yates
Eagle Rock
Deadwood
Ft. Bennett
Huron
Yankton
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Salt Lake City
Cheyenne
North Platte
Sacramento
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Prescott
Santa Fe
Ft. Elliott
San Diego
Yuma
Ft. Apache
Ft. Sill
Tucson
Silver City
Denison
El Paso
Ft. Stockton
Ft. Concho
San Antonio
Eagle Pass
Brownsville

Absolute Humidity
for
July
1876–1886

...ll figures show the number of
...s of water to each cubic foot of air.

CHAPTER VI.

THE WIND, AND HOW MEASURED.

The apparent capriciousness of wind has given rise to many proverbs as to its variableness, and until recent advances in meteorology no one questioned the truth of the saying: "The wind bloweth when it listeth, and thou canst not tell whence it cometh and whither it goeth." Observations and research show, however, that winds are subject to definite laws.

The direction of the wind is designated by the point *from* which it blows, as north, north-by-east, etc. In general, the wind is recorded to the eight principal points of the compass, but in more exact observations it is recorded in degrees of azimuth, as N. 10° E. or ten degrees east of North. In determining the point from which the wind is blowing, great care must be taken to use *true* bearings only. If this is not done the error may sometimes be a serious one, since the wind blowing from the same direction might be recorded at Eastport, Me., by compass bearings as northwest, and at Olympia, Wash. Terr., as north. This results from the well-known fact that the magnetic needle points absolutely to the North Pole only in a few places, and that elsewhere it has a variation either to the east or the west of the true north. In Table No. 6 will be found the present magnetic variations at principal points in the United States.

The wind-vane should rise above all surrounding buildings or objects, so that the wind may act freely upon it. The vane itself should be long and light enough to be easily moved, its support exactly perpendicular, and its bearing kept well oiled. The vane should balance on its support, and its tail should present a much larger amount of surface than its head, since the directive tendency depends upon the difference of the wind's action upon the head and tail.

Various devices have been used for registering the direction of the wind. Draper, Beck, Wild, Osler, and others have invented methods quite as ingenious but more complicated than the simply mechanical apparatus of Eccard. In this case the prolongation of the vane through the roof terminates at its lower end in a toothed wheel, which is geared into a second. The latter wheel is at the top of an endless screw, which moves up or down as the vane swings to and fro, a pencil pressing constantly against and recording on a paper-covered drum turned by clockwork once each day. The only defect arises from the records of calm and light steady winds being undistinguishable.

The most satisfactory record is that obtained from a modification of Gibbons's electrical self-registering anemometer. By increasing the number of magnetic circuits to four and enlarging the drum (see Fig. 11) as each mile of wind is recorded, its direction is also indicated either by letter, as N., N.E., etc., or by a dot or mark on the corresponding direction lines.

Of even greater importance than the direction of the wind is its force, which may be measured directly by its pressure or its velocity by instruments called anemometers. The oldest method of observing the force of the wind is by estimation, a somewhat rough but necessary mode in the absence of modern instrumental appliances. The scale devised by Sir Francis Beaufort

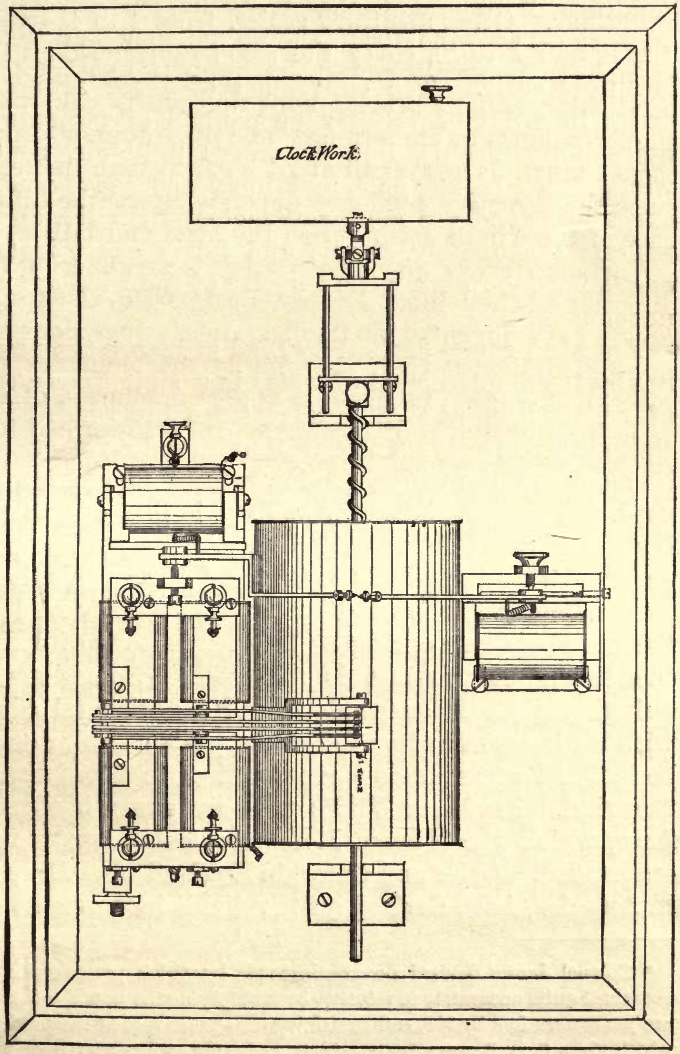


FIG. 11.—SELF-REGISTER FOR RAIN, DIRECTION, AND VELOCITY OF WIND.

is in quite general use, running from 1, light air, to 12, hurricane. Other arbitrary scales, from 1 to 4, 1 to 6, 1 to 8, and 1 to 10, cover the same range as does the Beaufort scale. The conversion of these arbitrary scales to miles of velocity or pounds of pressure is quite impracticable, but the words light air, gentle wind, strong breeze, gale, and hurricane convey more exact ideas and are more satisfactory than the above scales. Fortunately, simple and fairly exact instruments for determining the velocity of the wind are not uncommon.

The wind gauge devised by Lind measures the pressure by the displacement of water in a siphon, one end of which, bent at right angles, faces the wind. The siphon turns freely on a vertical axis, and a vane keeps its mouth to the wind ; the instrument is now rarely used. A more satisfactory method is that of measuring the pressure of the wind on a plane surface perpendicular to the wind's direction.* The plate, kept perpendicular to the wind by a vane, when moved by the wind acts on a spring or lever, by means of which the degree of pressure is measured. Sometimes a swinging plate is suspended by its horizontal edge, with its lower edge free to remain perpendicular or to be inclined at an angle corresponding to the force of the wind. Professor Wild's pressure gauge is of this form, which the Vienna Meteorological Congress recommended. Osler and Cator, in England, and Draper, in America, have devised quite reliable instruments on

* Colonel James devised a convenient rule by which pressure can be converted quite accurately to velocity, by multiplying the pounds of pressure per square foot by 200, and extracting the square root of the product, which gives the miles per hour. Conversely, the square of the velocity in miles per hour multiplied by .005 gives the pounds of pressure to each square foot.

the principle of pressure, and the records of these instruments, made by violent gusts, are most satisfactory. Unfortunately, they cannot be considered as absolutely accurate, since readings of separate instruments are not strictly comparable, as different instruments of the same pattern, with the same size of plate, have given discordant results. It is also well known that the force exercised by the wind upon each square foot of surface depends upon the size and form of the plate, and, perhaps, upon other conditions.

The velocity anemometer which most generally commends itself is that devised by Dr. Robinson (Fig. 12).

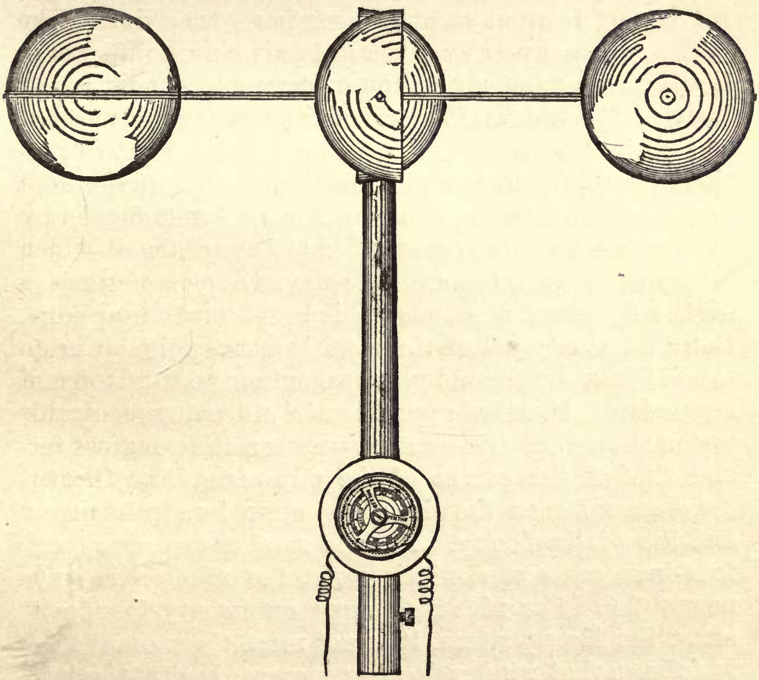


FIG. 12.—ROBINSON'S ANEMOMETER.

At the ends of two horizontal rods, crossing each other at right angles, are fastened four hollow hemispheres, with their open surfaces in the same direction, so that they may receive the wind freely. These cups are supported on a vertical rod, which is so mounted with bearings that it turns freely in a hollow tube and sets in motion by an endless screw at its lower end a set of index wheels.

The dials of the index wheels are so arranged that they show every mile of wind which passes. By means of an electrical device invented by Lieutenant Gibbon, United States Army (see Fig. 11), each mile of wind is recorded on a properly ruled blank form, which, revolving on a drum, contains the record for a day.

The anemometer should be kept in a vertical position and at such a height as to expose it to the full force of the wind. It should be kept free from dust and dirt and be carefully oiled, so as to prevent friction and injury to the different bearings, and the dial screw, while kept tight, should not be sufficiently so to interfere with the free motions of the dials.

The gearing of the dials for the mileage registration of the Robinson anemometer is based on the supposition that the travel of the wind is exactly three times the distance travelled by the centre of the cups. This supposition is only approximately true, as experiments show that the relation between the wind travel and that of the centre of the cup varies from 2.3 to 3.0, depending on the size of the cups, length of arms, and the wind velocity. For the smaller anemometers, four-inch cups on six-inch arms, the relation is very nearly 3.0. For nine-inch cups on twenty-four-inch arms, the Kew pattern, it is not more than about 2.5. It follows that wind velocities measured with the latter instruments, which are always geared to give three times the travel of cup, must be, at least, twenty per cent too high.

The ratio between wind travel and cup travel diminishes as the velocity of the wind increases. While 3 may be a correct ratio for an instrument when the wind is four miles an hour, the ratio may not be more than 2.5 for winds of thirty miles an hour.

In anemometers having short arms and large cups, the ratio for all velocities, high and low, is more nearly constant than in the case of long-armed instruments, as at higher velocities the cups on short arms shade each other in parts of their revolutions.

It is especially important that the anemometer should have a free, open exposure at such an elevation as to insure the instrument receiving the full force of the wind. The elevation is an important consideration, since the velocity of the wind increases quite regularly up to one thousand feet.

The average daily velocity of the wind is obtained similarly to other daily means, but, as a rule, the diurnal variation of the wind is so great, as will be seen in a later chapter, that its interest is secondary to that of the means of the hours of greatest and least velocity. In some instances over half the wind of the day blows during seven or eight hours.

CHAPTER VII.

PRECIPITATION—FOG, CLOUD, RAIN, AND SNOW.

The precipitation of the aqueous vapor of the air may be divided into two general conditions, the first of which obtains when the vapor is visible in the air, occurring in the shape of mist, fogs, and clouds ; or, secondly, when it reaches the surface of the earth, in the form of dew, hoar-frost, rain, snow, sleet, or hail. Mists, fogs, and clouds are of the same general class ; the cloud differing only from the mist or fog by its height and the changed conditions which arise from the cold of elevation. The water particles which make up these visible forms of aqueous vapor are of a minute size, being estimated to vary from .0006 to .0050 inch in diameter.

It was formerly advanced that these minute drops of rain or fog were vesicular—that is, hollow spheres ; but later experiments and observations go to show that not only are they solid bodies, but that they form around some minute particle of dust in the atmosphere.

Fog and cloud are supported in the air partly by the upward tendency of the air currents, partly by the resistance of air to the falling of minute spherical bodies, which is doubtless increased by the varying density of the different strata of air. When ascending air currents cease, the particles immediately commence to fall by their own weight, and frequently in so doing are again converted into aqueous vapor by passing into a stratum of air of a higher temperature, which is not in a state of saturation. These phenomena are visible any summer day, when but slight observation is necessary to note the continually changing shapes and forms of the clouds, which either diminish or increase, never remaining uniform and stationary.

Mists and fogs are generally of local distribution, and are produced by two methods: first, by warm, very moist winds blowing over the surface of cold water, and, second, by cold winds passing over very warm water or damp, moist ground. Consequently fogs occur with the greatest frequency in those regions, on or near large bodies of water, where great differences in temperature are found in comparatively short distances.

Within the Arctic circle the continued presence for the months of the summer sun is not marked by fair, bright days, but, on the contrary, fogs are almost constantly present over the sea, and the sun is hidden for many successive days. Such fogs are frequently only 150 to 200 feet deep, and from the high ground near Fort Conger the author, from 1881–83, rarely saw the adjacent ice-filled straits free for any prolonged period from low-lying sheets of fog and mist. In winter these vapors overhung the ice-cracks or tide-holes, but in summer they were quite general, except in windy weather. Scoresby notes that in 1817, among open ice in the Greenland Sea, he experienced a fog which never once cleared for fifteen days, while in 1821, from July 11th to August 21st, an interval of forty-one days, three days only were free from fog.

On the North Pacific coast fogs prevail during winter, and their advent, coincident with the rains, marks the beginning of the rainy season. They come with quite a degree of regularity at New Westminster, B. C., about the middle of October. These fogs in California are sometimes over 1500 feet thick, and their advent and passage over the interior valleys do not a little to relieve the aridity of the country. As much as .05 of an inch of water in depth has been deposited by fog in a single night.

Along the Atlantic coast fogs are most prevalent from the New England coast northeastward to Newfoundland, increasing in density and frequency as one goes northward. It has long been known that the fog conditions upon these coasts are caused by the winds, warmed and vapor-ladened by their passage over the Gulf Stream, being drawn over the cold surface current which flows along these coasts. Sergeant Garriott, of the Signal Service, has lately defined more clearly the cause of these fogs, and has shown that they have a definite relation to the advance and passage of low area storms over the United States and Newfoundland. The fog is found only in the east and south quadrants of these storms, so that its coming and passing is intimately connected with the storms themselves, and can be predicted with a fair degree of certainty several days in advance.

CLOUDS.

The numberless forms of clouds make it difficult to so classify and name them as to secure easy recognition and ensure uniformity of record. The fair-weather, the thunder and rain clouds are such forms as impress even the casual observer, and give very definite indication of the coming weather ; but such expressions do not convey to meteorologists clear, definite ideas as to the exact shape, definite formation or approximate elevation of the clouds observed.

The necessity of an exact, comprehensive, but simple nomenclature has long been apparent, but despite the efforts of several distinguished meteorologists, particularly Hildebrandsson and Ley, all attempts to reform and extend the present system have failed.

The present classification, of three simple and four compound forms, is that of Luke Howard, and has remained unchanged since its introduction in 1803.

The *cirrus*, always of great elevation, is a cloud of fibrous form, and is characterized by its great variety in shape, a marked delicacy of substance, and its singularly pure white texture.

The *cumulus*, of moderately low elevation, especially the cloud of a summer day, assumes in its simpler form the shape of conical heaps rising from a horizontal base. It may be seen in warm afternoons rising with an ascending air current in huge masses, meeting and drifting with horizontal currents. When these clouds gradually dissolve they indicate fine weather. In other cases the clouds increase in size and extent, while the woolly white texture of the cloud gradually assumes a darkish tint.

The *stratus* is the lowest of all, generally gray masses or sheets of cloud with illy-defined outlines.

The term *nimbus* is applied to any cloud or clouds from which rain or snow is falling.

There is a form of cloud partaking of the characteristics of both cirrus and cumulus, which is called the *cirro-cumulus*. Its most striking form, small round masses of cloud, apparently cirrus bands broken and curled up, is commonly known as the mackerel sky.

When the cirrus arranges itself into thin horizontal layers, it is called *cirro-stratus*. This formation is frequently of great extent, but so thin perpendicularly that the sun's rays frequently pass quite through it.

The *cumulo-stratus* is the cumulus blended with the stratus. Its most remarkable form is in connection with approaching thunder-storms, often called thunder-heads, when it frequently presents a magnificent spectacle in its beautiful form, strong contrasts of light and shadow, and rapidly changing outlines.

The cirrus, cirro-cumulus, and cirro-stratus, named in order of occurring altitude, are known as upper clouds, the others as lower clouds.

Messrs. Ekholm and Hagström have given careful attention to the elevation of the various kinds of clouds, and from over 1400 measurements deduced the following conclusions as to extreme limits of elevation :

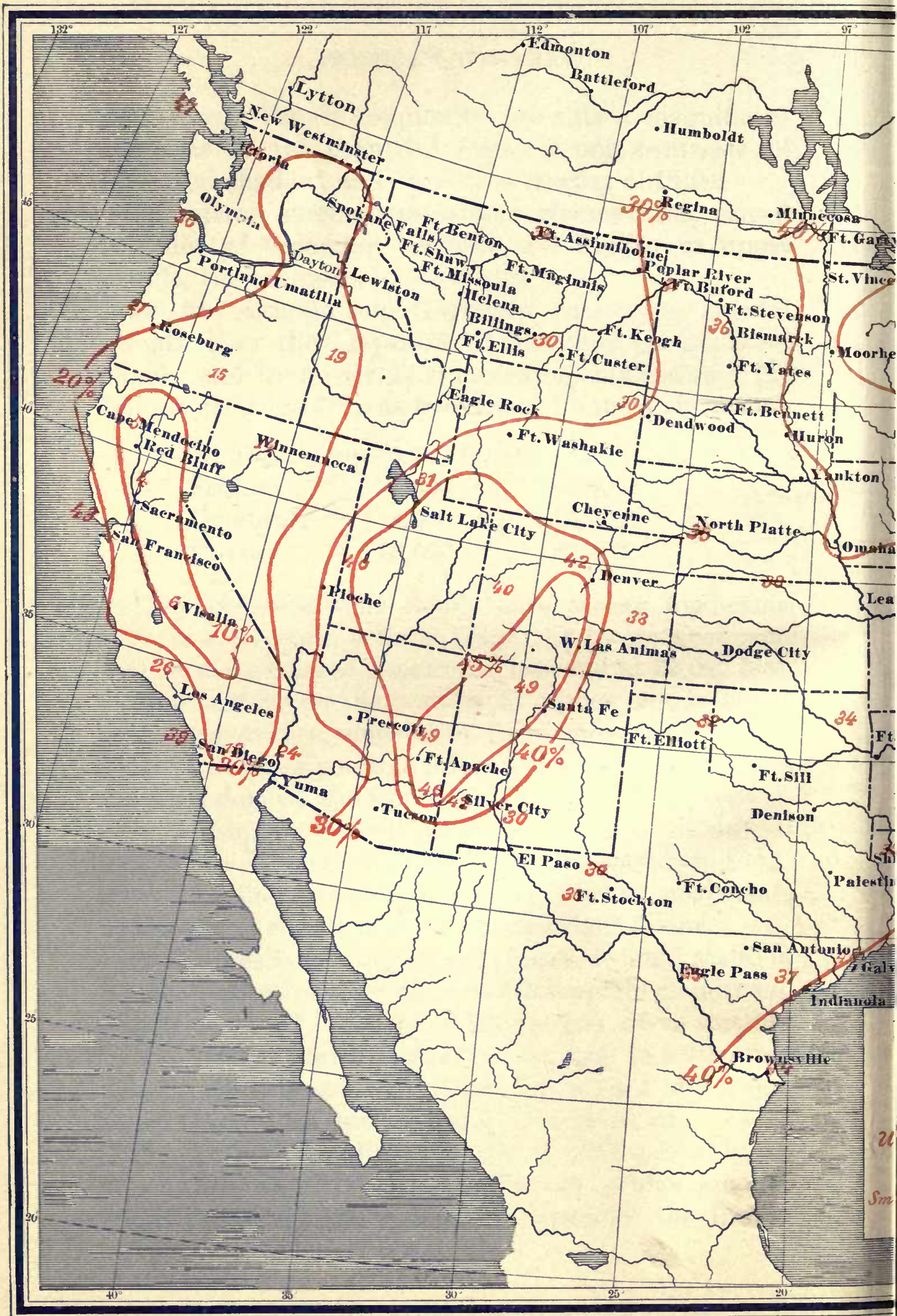
Nimbus,	from	3,700	feet	to	7,200	feet.
Stratus,	"	600	"	"	3,500	"
Cumulus,	"	4,900	"	"	14,000	"
Cirrus,	"	18,000	"	"	22,400	"

They observed that clouds have strong tendencies to form at a certain definite height, and were most common at elevations of about 5000 feet and at 22,000 feet.

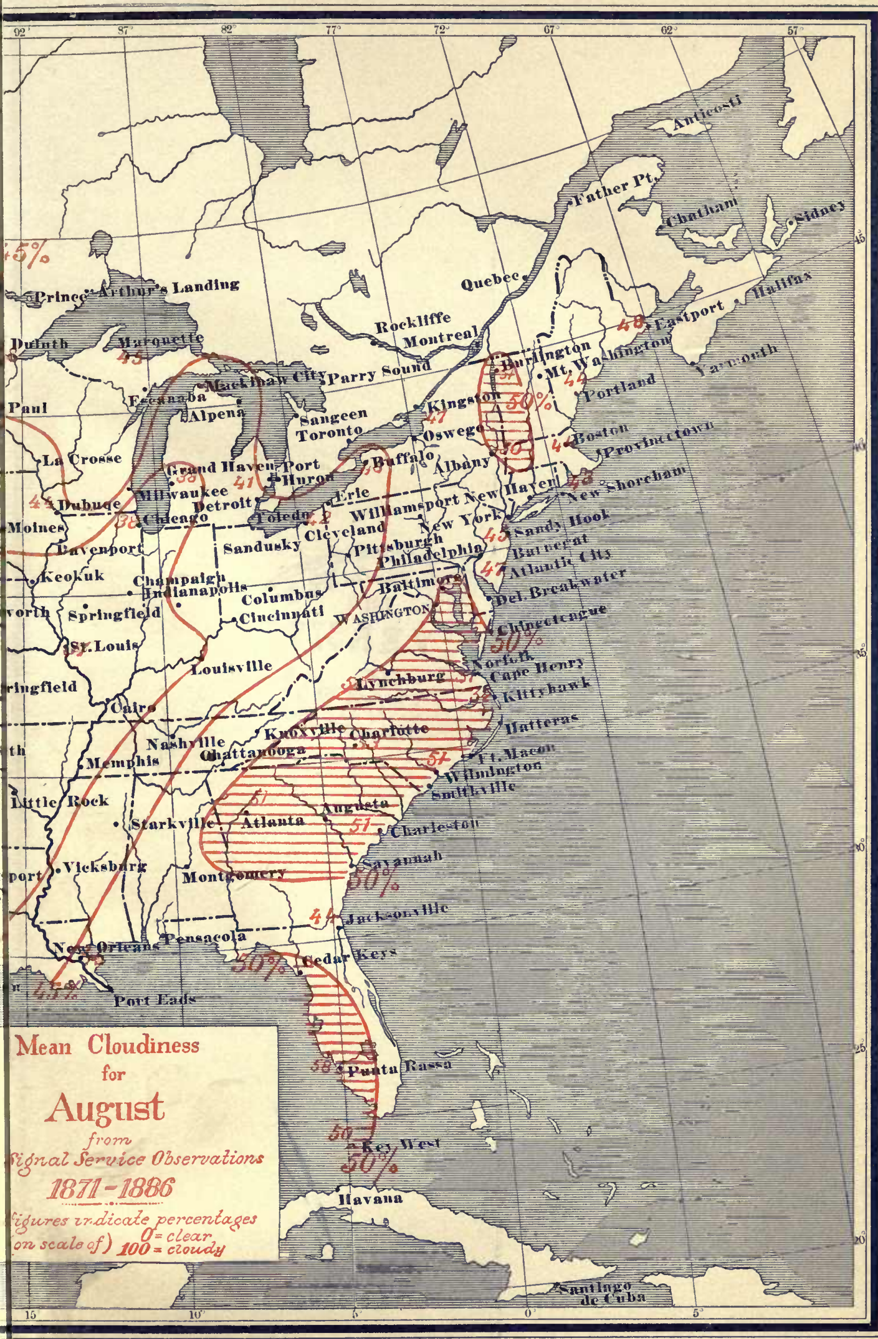
Observations on the motions of upper clouds are of great importance, since from these movements can be gleaned the only possible information as to the prevailing direction of the upper air currents. This knowledge is valuable, since it must shed light on general atmospheric currents, and also may lead to better methods of weather forecasts in which abnormal movements of the cirrus clouds may be an important factor.

Cloudiness is usually recorded on a decimal scale, in which 0 indicates clear sky and 10 complete cloudiness. Fog is recorded "foggy" when spoken of as weather by the United States Signal Service, but in estimating cloudiness, it is recorded as zero when light or broken, but if it envelops everything it is recorded 10.

The average cloudiness of the earth is probably between fifty and fifty-five per centum, which amount slightly exceeds the cloud conditions of the United



Edmonton
Battleford
Lytton
New Westminster
Humboldt
Victoria
Olympia
Spokane Falls
Regina
Minnecosa
Ft. Benton
Ft. Shaw
Ft. Assinniboine
Ft. Missoula
Ft. Maginnis
Poplar River
Ft. Buford
Dayton
Lewiston
Portland
Umatilla
Helena
Ft. Stevenson
Billings
Ft. Keogh
Bismarck
Roseburg
Ft. Ellis
Ft. Custer
Ft. Yates
St. Vince
Moorhe
Eagle Rock
Ft. Bennett
Deadwood
Huron
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Yankton
Sacramento
San Francisco
Salt Lake City
Cheyenne
North Platte
Omaha
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Santa Fe
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Tucson
Denison
El Paso
Ft. Stockton
Ft. Concho
Palestin
San Antonio
Eagle Pass
Indianola
Brownsville
20%
30%
40%
45%
10%
132°
127°
122°
117°
112°
107°
102°
97°
45°
40°
35°
30°
25°
20°



Mean Cloudiness
for
August
from
Signal Service Observations
1871-1886
Figures indicate percentages
(on scale of) 0 = clear
100 = cloudy
Prince Arthur's Landing
Duluth
Marquette
Escanaba
Mackinaw City
Alpena
Parry Sound
Sangeen
Toronto
Rockliffe
Montreal
Quebec
Father Pt.
Anticosti
Chatham
Sidney
Halifax
Eastport
Yarmouth
Burlington
Mt. Washington
Portland
Boston
Provincetown
Kingston
Oswego
Albany
Buffalo
Grand Haven
Port Huron
Milwaukee
Detroit
Chicago
Dubuque
La Crosse
Davenport
Keokuk
Toledo
Erie
Sandusky
Cleveland
Williamsport
New Haven
New Shoreham
New York
Sandy Hook
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Baltimore
Del. Breakwater
WASHINGTON
Chincoteague
Champaign
Indianapolis
Columbus
Cincinnati
Springfield
St. Louis
Louisville
Lynchburg
Norfolk
Cape Henry
Kittyhawk
Hatteras
Cairo
Nashville
Knoxville
Charlotte
Chattanooga
Memphis
Ft. Macon
Wilmington
Smithville
Little Rock
Starkville
Atlanta
Augusta
Charleston
Savannah
Vicksburg
Montgomery
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
45%
50%

States to the east of the Mississippi River. To the westward the yearly percentages more generally range from thirty to forty-five.

In the Pacific coast and Southern Plateau regions are found sharp contrasts, and decided departures from the mean percentages elsewhere. In Western Texas, New Mexico, Arizona, and California, the average annual percentages of cloudiness range from twenty per cent to thirty per centum. In Southeastern California and the Valley of the Colorado obtains the minimum amount of cloud in the United States, the percentages being only nineteen for Keeler, Cal., and seventeen for Yuma, Ariz. Along the Pacific coast to the northward of California, however, the percentages increase very rapidly; being sixty-two at Olympia and Tatoosh Island, and probably the increase is constant northward to Alaska, since at St. Michael's the percentage is sixty-seven, and at Unalaska rises to the extraordinary figure of eighty-two.

Eastward of the Mississippi River the largest percentages of cloudiness are found on the shores of Lake Ontario, ranging from sixty at Buffalo to sixty-three at Oswego.

The monthly fluctuations of cloudiness are of greater importance than the mean cloudiness for the year.

Over the greater part of the area of the United States the minimum amount of cloudiness for a month occurs during August, and in consequence the cloudiness of that month has been charted, No. XVII., as one of the representative months of the extremes. Over a small portion of the upper lake region July has a slightly less quantity of clouds than August; while in the Atlantic States, from New Jersey to Northern Florida, the least clouds are observed during October.

The maximum amount of mean cloudiness by months is illustrated by the chart, No. XVI., for January, since during that month the greatest amount of cloudiness prevails over the Pacific coast region and in the South Atlantic and Gulf States. From New England westward to Michigan and Illinois the cloudiness is slightly greater during December, while in the Missouri Valley and the Rocky Mountain region the maximum cloudiness falls during the months of March, April, and May.

In Fig. 13 is shown the mean cloudiness for the different months of the year, deduced from many years' observations at certain stations in the United States. As might be expected, the cloudiness as a rule is much more prevalent in winter than in summer. There are notable exceptions to this rule, which show that locality has much to do with the shape of the curves. It will be noticed that the curves at San Francisco and Yuma are in general accord, with a marked increase of cloudiness during July and August; but at Olympia and Sacramento, both in the Pacific coast region, the shape of the curves, with the minimum in July and August, are more in accord with those for the rest of the country.

The most striking case of extreme cloudiness is that at Unalaska, where the sky was almost entirely covered in February, 1880, there being but three per cent of clear sky during the month. In many other separate months the cloudiness of this station has ranged from ninety-one to ninety-three per centum.

In certain localities in the western part of the United States, the sky is almost cloudless in certain months of the year. At Yuma the percentage of cloudiness for June and September is but nine, and in some years during these months the percentage has been as low as one. The months of June to September are al-

Edmonton
Battleford
Humboldt
Regina
Minnecosa
Lytton
New Westminster
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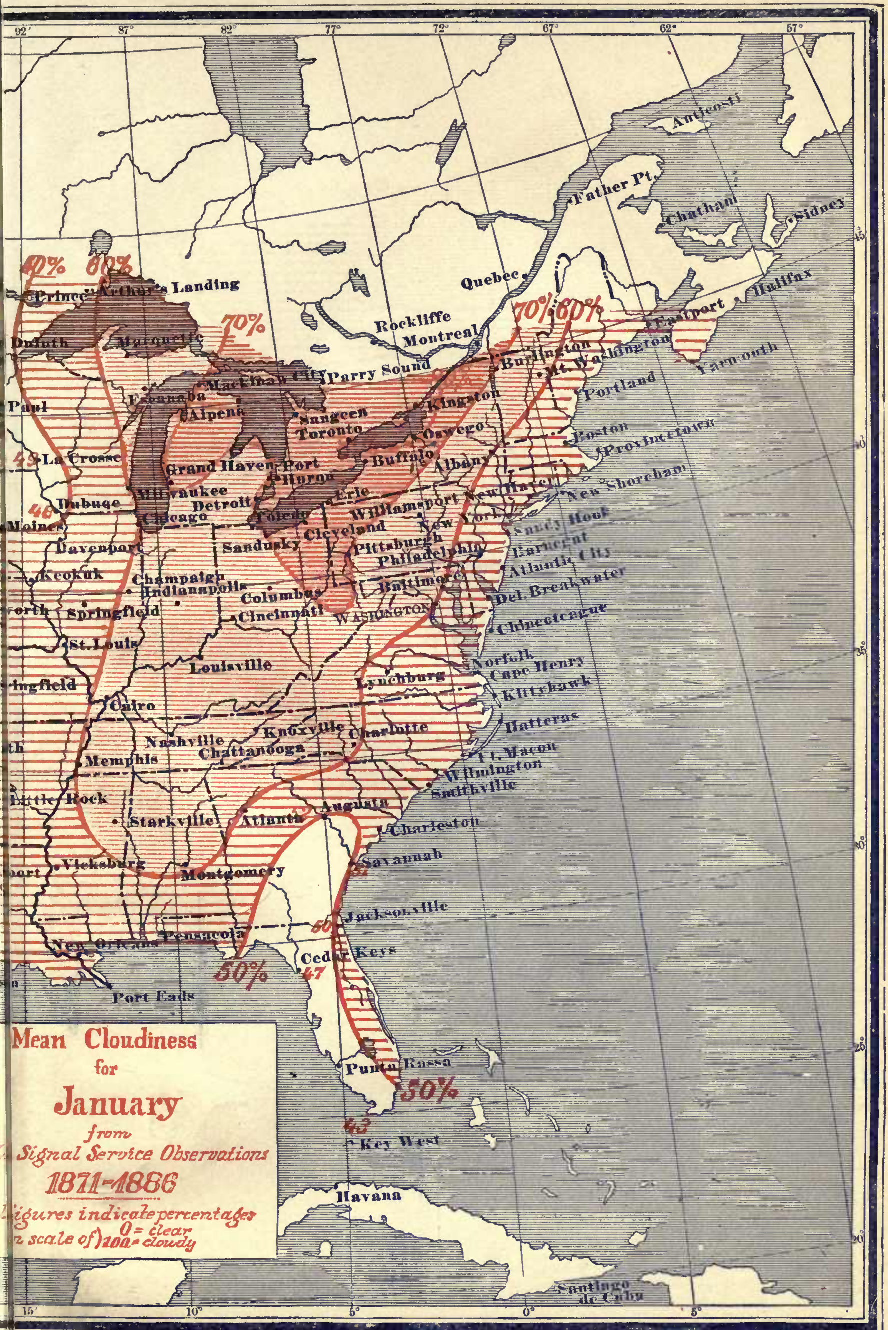
Olympia
Spokane Falls
Ft. Benton
Ft. Shaw
Ft. Missoula
Ft. Assiniboine
Ft. Maginnis
Helena
Dayton
Lewiston
Portland
Umatilla
Poplar River
Ft. Buford
Ft. Stevenson
Bismarck
Ft. Yates
Moorhe
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Roseburg
Eagle Rock
Ft. Washakie
Deadwood
Ft. Bennett
Huron
Yankton
Cape Mendocino
Red Bluff
Winnemucca
Salt Lake City
Cheyenne
North Platte
Omaha
Sacramento
San Francisco
Visalia
Pioche
Denver
W. Las Animas
Dodge City
Los Angeles
Prescott
Santa Fe
Ft. Elliott
Ft. Sill
San Diego
Yuma
Ft. Apache
Tucson
Silver City
El Paso
Denison
Ft. Stockton
Ft. Concho
Palestin
San Antonio
Eagle Pass
Indianola
Brownsville
70%
60%
50%
40%
30%


Mean Cloudiness
for
January
from
Signal Service Observations
1871-1886
Figures indicate percentages
on scale of) 0 = clear
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40%
60%
70%
70%
60%
50%
50%
Prince Arthur's Landing
Duluth
Marquette
Mackinaw City
Parry Sound
Escanaba
Alpena
Saugeen
Toronto
Kingston
Oswego
Buffalo
Albany
La Crosse
Grand Haven
Port Huron
Milwaukee
Detroit
Dubuque
Chicago
Toledo
Erie
Williamsport
New Haven
New York
Cleveland
Sandusky
Pittsburgh
Philadelphia
Davenport
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Washington
Springfield
Cincinnati
St. Louis
Louisville
Lynchburg
Norfolk
Cape Henry
Kittyhawk
Cairo
Hatteras
Nashville
Knoxville
Charlotte
Chattanooga
Memphis
Wilmington
Smithville
Little Rock
Starkville
Atlanta
Augusta
Charleston
Vicksburg
Montgomery
Savannah
Jacksonville
New Orleans
Pensacola
Cedar Keys
47
Port Eads
Punta Rassa
43
Key West
Havana
Santiago de Cuba
Quebec
Rockliffe
Montreal
Burlington
Mt. Washington
Portland
Boston
Provincetown
New Shoreham
Sandy Hook
Barnegat
Atlantic City
Del. Breakwater
Chincoteague
Eastport
Halifax
Yarmouth
Father Pt.
Chatham
Sidney
Anticosti
92°
87°
82°
77°
72°
67°
62°
57°
15°
10°
5°
0°
5°

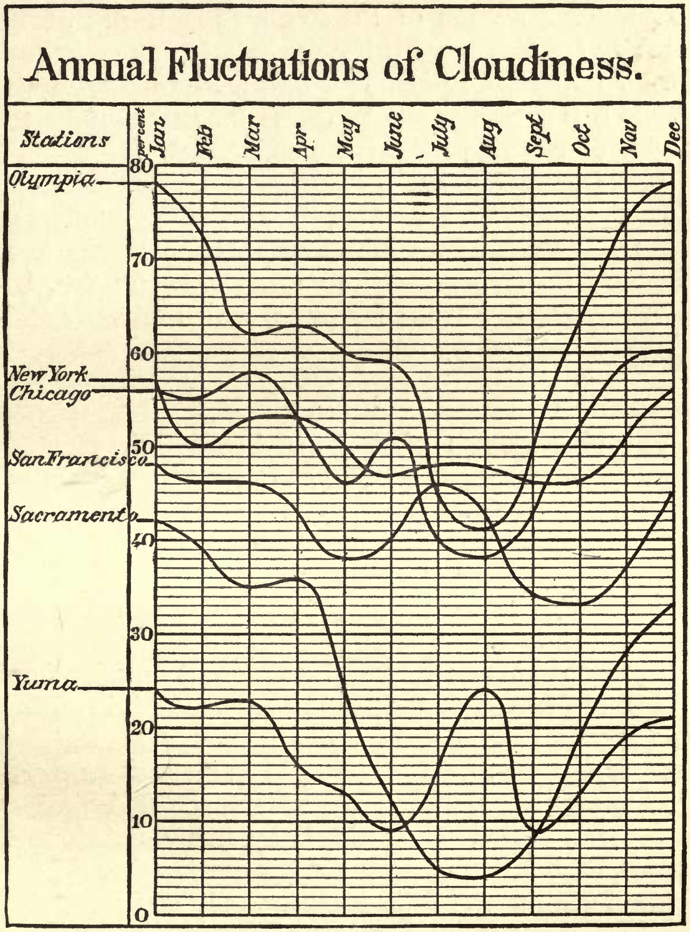


FIG. 13.

most cloudless both at Keeler and Sacramento, Cal., where the percentages range between four and nine.

The total absence of rain and the practical absence of clouds for months at a time was formerly considered to make this section of the country practically worthless; but of late years it has proved of great advantage for an important industry of Southeastern California, where this exceptionally sunshiny weather permits the curing of raisins without artificial means.

Little attention has been paid to the diurnal variation of cloud, but according to Buchan a maximum, more pronounced over the ocean than on land, occurs about sunrise. The minimum is about mid-day, followed by an afternoon maximum, which falls by midnight to a secondary minimum.

DEW.

The phenomenon of dew was involved in mystery until 1814, when an American, Dr. W. C. Wells, then residing in England, by his ingenious and careful experiments discovered the conditions under which dew forms. Dr. Wells propounded a "Theory of Dew" which fully explained the phenomenon, and which is accepted as final.

To inhabitants of great cities the most familiar form of dew is that which gathers in the shape of tiny drops on the outside of glasses and other vessels containing cold water, when they are exposed in a close, comparatively warm room, when the air is moist. This process is vulgarly called "sweating" by many uninformed people, who believe that the water exudes through the sides of the vessel. It is, however, only an illustration of the formation of dew, the warm, moist air being chilled, by contact with the cold sides of the vessel, below the *dew-point*—*i.e.*, acquiring such a low temperature that it can no longer hold its moisture as aqueous vapor, and so deposits it on the cool surface as dew. If the air in the room is very dry no dew is formed, no drops appear.

The same process as is here described takes place every clear calm night over the greater part of the land surfaces of the earth. The chapter on radiation sets forth the method in which the earth's heat escapes into space. When the relative humidity of the air is high it requires but slight loss of heat to reduce the temperature of the air below the dew-point. Such action takes place with the greatest rapidity over grasses and similar vegetation which radiate heat rapidly, and the process is facilitated by light air coming from humid quarters, whereby the air which has given up part of its moisture is speedily replaced. The economy of nature is thus shown in the formation of dew, as in other physical laws, since the enormous radiating powers of vegetable substances, which most need moisture for growth and development, ensure their receiving the greatest possible amount of dew.

The formation of dew is retarded by any condition which obstructs radiation, such as a covered or partly shaded sky, whether by cloud, foliage, or other intervening object, or by the presence of wind when the constantly moving and mixing air does not remain in contact with the cold surfaces long enough to be chilled below the dew-point.

Dews are the heaviest in low latitudes and along coasts where the prevailing night breeze is from the sea, since the air passing over the earth is then not only vapor-laden to such an extent that the temperature of the dew-point is nearly the same as that of the air, but, from its high temperature, the air contains a large amount of aqueous vapor.

The amount of dew which falls varies nightly from zero to perhaps .02 inch according to local conditions. But few systematic observations have been made with a view to determining the exact amount, which has been estimated for the British Isles to be not far from an inch and a half for the year.

The dews along the California coast occur under favorable conditions of clear sky, with light airs from the ocean, and so are unusually heavy—a fortunate circumstance, which materially ameliorates the effects of the almost rainless summer.

When the dew-point of the air is at a temperature below the freezing-point, the moisture then condensed is deposited on the colder radiating surfaces in a solid form, as *hoar-frost.*

RAINFALL.

Rainfall is the most indefinite of the various meteorological phenomena, as to its locality, distribution, seasonal recurrence, and amount. It is impossible to draw a sharp line between mist and rain. Whenever condensation of aqueous vapor takes place rapidly and the small particles of mist increase in diameter it is then called rain. The exact manner in which rain forms is not known. Different theories have been advanced, some assuming that two masses of saturated air of different temperatures are suddenly combined, with the result of immediately condensing the excess of moisture which necessarily results. Others urge that rainfall usually occurs by the cold of expansion or elevation, owing to large masses of saturated air being forced upward by under-running currents of cold air, or by violent out-draughts of warm air from the upper strata of the atmosphere, which naturally draw upward the saturated air. Doubtless both methods obtain to a greater or less extent, and it is susceptible of proof that the heaviest rains of the world are caused by the cold of expansion, where the general movements of the atmosphere result in warm moist air being forced or drawn up to great elevations by the presence of abrupt mountain ranges, over which the air must pass and in so doing lose the greater part of its vapor. The author believes in the general law advanced by Blanford, that "however vapor-ladened may be any current of air, however saturated, it does not bring rainfall so long as it preserves a horizontal movement." Either increased elevation, or eddies from increase of friction, or the convection around borders of a barometric depression causes formation of cloud and rain.

Excessive rainfall on land occurs at places in middle or lower latitudes contiguous to a sea of comparatively high mean temperature and from which the prevailing winds blow. The heavy rain results from the condensation of moisture by cold, caused, as some suggest, partly by the winds passing over a land of lower temperature, or, as is more probable, by being forced upward, more or less sharply, by the configuration of the country.

The author, from a somewhat extensive observation of weather conditions, fails to find any cases where the vapor-ladened air is apparently cooled to any extent by radiation or convection from land of low temperature. The process of cooling a body of moist air by its own radiation into space, or by convection or radiation from cold land, must be very slow, and the final effect inconsiderable; especially as compared with the cold of elevation, which is about half a degree for every hundred feet of ascent.

Deficient rainfall over land occurs in high latitudes, where the mean temperature of sea and air are both low. In low latitudes it results from the prevalent winds having been deprived of the greater part of their moisture by having passed over mountain ranges of considerable elevation, or by their passing over a country having nearly the same temperature as the region from which the moisture was drawn, and where the country does not rise with marked abruptness. Tranquil atmospheric conditions arising from the absence of low areas, or exemption from their influence owing to intervening and obstructing mountain ranges, tend greatly to reduce the amount of rainfall.

Rain or snow from a cloudless sky sometimes occurs, and is called *serein;* it is nearly always small. Buchan cites a case from the experience of Sir J. C. Ross (the famous Arctic traveller), on Christmas Day, 1839, near Trinidad, when a light shower of nearly an hour prevailed without a cloud in sight. Similar cases have not been infrequent in the United States, where over twenty have been observed. It often suggested that the rainfall may be from thin and translucent clouds. Professor T. Russell, in examining nearly one hundred cases of rain and snow from a clear sky, found that the larger number occurred "on the southwest side of an area of low barometer, . . . at a distance of about five hundred miles from its centre." Frequently high winds prevail, so that the snow could be carried from a cloudy region in the upper air.

On June 30th, 1877, a heavy shower at Vevay, Ind., lasting five minutes, fell from an apparently cloudless sky. The rain-drops were of large size, and, as caught on a sheet of blotting-paper, made circles two and a half inches in diameter. Nearly three fourths of an inch of snow fell from a clear sky on March 15th, 1885, at Bloomington, Ill.

In the experience of the author at Fort Conger, Grinnell Land, 81° 44′ N., snow or frost fell almost daily during the prolonged cold spells in midwinter, when spiculæ of frost appeared to be continually in suspension in the mid-air. This snowfall and frost phenomena were attributed to the solid condensation of the aqueous vapor of the comparatively warm upper air by the layers being successively chilled partly by radiation and partly by contact with the cold underlying strata. It was invariably the case during prolonged cold that the upper strata of air, as shown by observations on adjacent mountains, were always warmer than at the bases.

There are occasional instances in which black, yellow, or golden rain are reported, as well as showers containing fish and animalculæ and insects of various kinds. In all these cases the foreign constitutents and color of the rain or snow are due to impurities gathered from the surface of the earth.

In March, 1879, several instances of yellow rain or snow occurred in the United States. At South Bethlehem, Penn., during the night of March 16th there was a slight fall of snow in that section, and on the next morning, when the snow had melted, a yellow deposit was found covering the ground, more or less. Upon examination the deposit was found to be the pollen of pine trees. The Signal Corps observer at New Orleans reported light showers on the 17th, and stated that "a peculiar feature of the rain was its yellow color, which was due to large quantities of the pollen of the cypress trees floating in the atmosphere." At Lynchburg, Va., yellow rain fell on March 21st, 1879, a sample of which was transmitted to the Surgeon-General United States Army for microscopical examination. Major J. J. Woodward, Surgeon United States Army, reported that "the yellow powder which gives it its physical properties consists entirely of the characteristic triple-grained pollen of the pine. The pine woods in the region around Lynchburg had been in blossom, I believe, for some days previous to the 20th, and the direction of the wind at the time should indicate where the pollen came from. Under favorable circumstances, however, the pollen may be carried for long distances, so that its source is not necessarily near the town."

Professor Weber gives an account * of golden snow on February 27th, 1877, in Peckeloh, Germany. He says:

"The snow did not appear white but yellow, and a kind of yellow which gave the appearance of a surface strewn with gold-dust. I took up some of the snow, put it into a porcelain dish, and allowed the snow-water to evaporate. A delicate yellow film settled upon the sides of the dish, very evenly distributed."

GREEN and RED snow are to be found in a few parts of the world, principally in the Arctic regions, the color being due to minute organisms called *Protococcus nivalis.* The most extensive deposits of red snow known, situated near Cape York, Greenland, were discovered by Captain John Ross, R.N., in 1818, from whom the hills, owing to this snow, received the fanciful name of Crimson Cliffs. The color, however, as seen by the author, is a faint, dirty, dull red, and not crimson.

RAIN GAUGES.

Rain gauges for ascertaining the quantity of rain which falls are of various forms, the simplest being the metallic cylinder of uniform diameter. The rain-water caught in this gauge is measured by a small glass tube, on which the relative proportions are scaled, so that the quantity caught may be measured to the hundredth of an inch. The standard gauge of the Signal Service is eight inches in diameter, and has a receiving area of fifty square inches. The tube of the gauge de-

* See Klein's *Wochenschrift,* 1877, pp. 130, 131.

taches from the lower part, as is shown in Fig. 14; the reservoir is a brass tube, with an area of only one tenth of the receiving funnel, so that every hundredth of an inch of rain caught fills the reservoir to the depth of one tenth of an inch. Gauges from three inches upward are satisfactory for rain observations, but those of less diameter are thought to register too little.

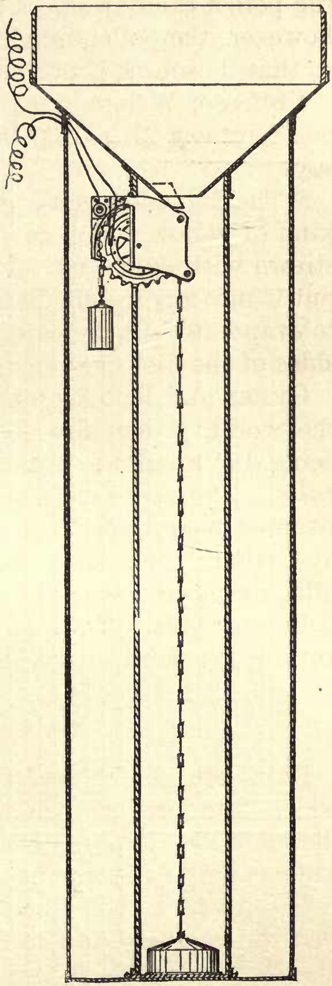


FIG. 14.—VERTICAL SECTION OF SELF-RECORDING RAIN GAUGE.

Self-registering rain gauges are generally complex, and are apt to work with some degree of irregularity. The Eccard Gauge, shown in Fig. 15, contains in the reservoir a float counterbalanced over a wheel with a certain weight, which, as the rain is gathered, closes an electric circuit for each hundredth of an inch that falls, and by a simple mechanism raises the weight so as to be in position to record the next hundredth.

The gauge adopted by the Signal Service, a standard gauge to which is attached the mechanism devised by Professor Marvin, is shown in Fig. 14. The chain connecting the weight in the reservoir runs over a wheel which has notched teeth fitting into the links of the chain. Whenever a tenth of an inch falls, the wheel turns one tenth, and in doing so makes and breaks an electric circuit by mechanism similar to that in use on the self-registering anemometer. Every tenth of an inch of rain is thus recorded by electricity. See Fig. 11. The elevation of the rain gauge above the ground was long thought to be an important point in its exposure, as the idea was advanced that the amount of rain which fell upon the ground was considerably greater than that which fell upon surfaces at considerable elevation. Later investigations have shown that less rain—from four to ten per cent—is gathered from instruments exposed on the roofs of houses and other high points through the action of the wind, the eddies of which, acting near the gauge, cause the rain to blow out of the receiver.

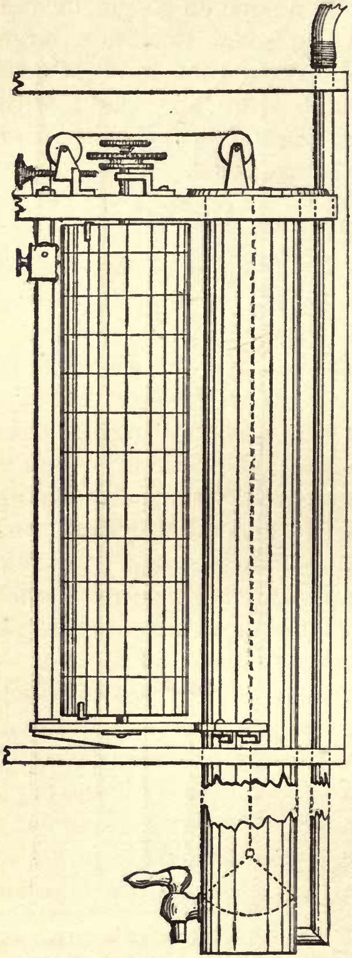


FIG. 15.—ECCARD'S RAIN GAUGE.

Experiments go to show that a gauge exposed in the middle of a large level surface, at considerable elevation, will catch as much rain as one on the surface of the ground. It is difficult, however, to obtain large level surfaces at high elevations, so that the best general exposure of a rain gauge is an open field, with the top of the gauge from eighteen to twenty-four inches from the surface of the ground.

SNOW AND HAIL.

Whenever the condensation of aqueous vapor takes place in temperatures below 32° F., the deposit is made in solid condition, known as snow or hail.

Snow is caught in a simple gauge, the diameter of which is uniform from top to bottom, and the contents when melted are measured either in the original rain gauge or in a receiving reservoir, the ratio of which is generally one to ten, as compared with the receiving surface of the snow gauge. In general it is estimated that ten inches of snow make one inch of rain; but this must be considered as only approximately correct, since the density and moisture of the snow has much to do with the quantity of the water yielded.

Snow is made up of separate crystals, most of which are of great beauty. The forms are always hexagonal, either of simple or compound forms, and great variety. When the snow is light and the weather cold, the crystals, if caught upon any soft material, can be easily and conveniently observed either by the naked eye or under a magnifying-glass. When thus caught the crystals are very regular and unbroken.

The experience of the author at Fort Conger showed that during any single storm the crystals were invariably of the same form, but possibly combinations of two forms may occur. When the temperature is very near 32°, so that the flakes are damp and the snow falls heavily, or is blown much by the wind, the crystals are broken, and the separate flakes unite to form large masses of snow. One of these compound snowflakes of remarkable size is said to have fallen at Chapston, Wales, January 7th, 1888, measuring 3.6 inches in length, 1.4 in breadth, and 1.3 in thickness, and when melted gave 2½ cubic inches of water.

Hail falls rather in the shape of ice than snow. There is a kind of soft hail, rounded pellets and of very soft grain, which falls in winter or spring. This seems to be rather frozen sleet, which itself is a mixture of snow and rain, rather than true hail. A distinction is made between this soft hail, as it is called, and true, hard hail, by meteorologists abroad ; in the United States this distinction is not always made.

The true hard hail is usually composed of alternate concentric layers of hard, transparent, and soft opaque ice. The stones, although of an irregular shape, yet in general are of a rounded character.

Several instances are mentioned when remarkable masses of ice—evidently formed by hailstones cementing together—fell in India.

Dr. Buist, apart from these masses of ice, divides hailstones into three classes : first, pure crystalline ice covered externally with an opaque coating ; second, the same as the first, except that in its interior is a many-pointed star ; third, nearly globular stones formed of thin concentric layers of varying transparency.

The accompanying illustrations, Fig. No. 16, A to E, show the structure of hailstones of various kinds. Fig. A shows a hailstone which fell in the storm of May 27th, 1869, near Bjeloi, Kleutsch, Caucasus. Figs. B and C are representations of hailstones which fell at

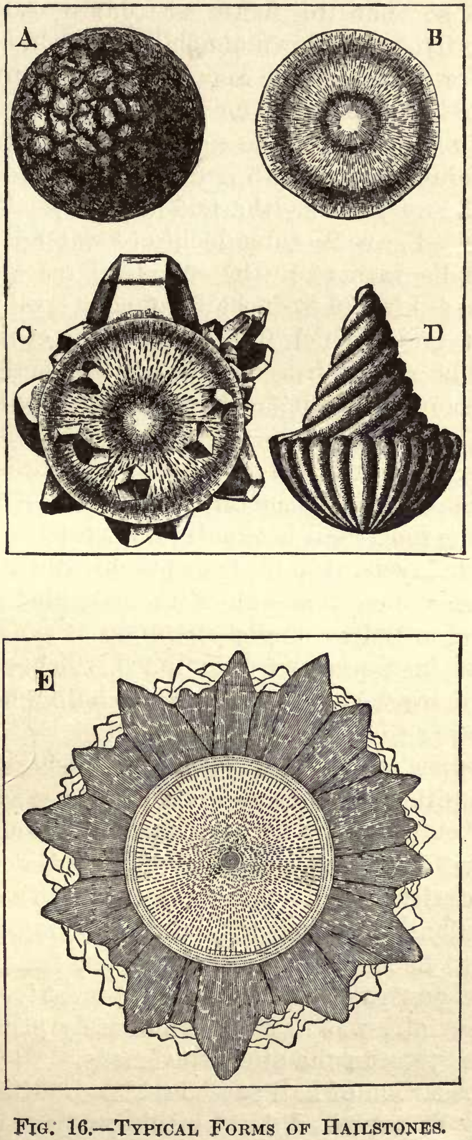


Fig. 16.—Typical Forms of Hailstones.

the same place on June 9th, 1869. Fig. E shows the appearance of a remarkable hailstone which fell, according to Captain Delcros, July 4th, 1819, at Braconniere, in the northwestern part of France. In Fig. D is shown the unusual form of a hailstone 2 inches long, $1\frac{1}{2}$ inches in diameter, which fell at Morgantown, W. Va., April 28th, 1877. This stone had an ice nucleus, with the remainder formed of ice and snow, and with fourteen others gave an average of 0.873 cubic inches of water to each hailstone. Stones of this formation have also fallen in France.

The specimens of hail shown in section in A, B, and C are described by Moritz, Director of the Tiflis Observatory.

They consisted of concentric layers of clear ice, alternating with softer porous layers of less thickness, around a very porous nucleus filled with air bubbles, and, consequently, opaque. The wreath-like formation of crystals around the periphery of the circle of C was in marked contrast with the formation inside the circle, and must indicate, at least, two distinctly different stages in the production of the hail.

C shows also a radial formation. There were six bright whitish radii at angular distances apart of exactly 60°. The spaces between the radii contained pure bluish-tinted ice, like glacier ice, filled with small pear-shaped cavities with the apices toward the centre of the hailstone. Viewed with a magnifying-glass they seemed to be free from air. Between the radii there were also groups of crystals of the purest ice.

The ice in E was much more densely packed about the centre than in the other specimens.

The formation of hail occurs under conditions which can only be surmised, but the alternations of opaque and transparent layers of ice show conclusively that very violent contrasts of temperature must exist, and that the stone passes alternately and repeatedly from moderately high to freezing temperatures. It would seem probable that hail is generated by the meeting of cold, very dry, and possibly descending currents, with moist and warm ascending ones.

Various theories have been advanced concerning the formation of hailstones, none of which, however, are considered as entirely satisfactory. Volta broached the theory that hail pellets were in a state of constant oscillation between two oppositely electrified clouds in which condensation was always going on, and that the stones grew in size until they fell to the earth by gravitation. Dove believed that hail-storms are always whirlwinds around a horizontal axis, whereby circulating currents carry the growing hailstones around and around, alternately into hot and cold air, whence gravitation eventually brings them to the earth. The growth in size and structure of hail is shown by its concentric layers, and makes it evident that the stone passes at least as many times as it has separate layers from a stratum of air having a high temperature to one having a correspondingly low one.

CHAPTER VIII.

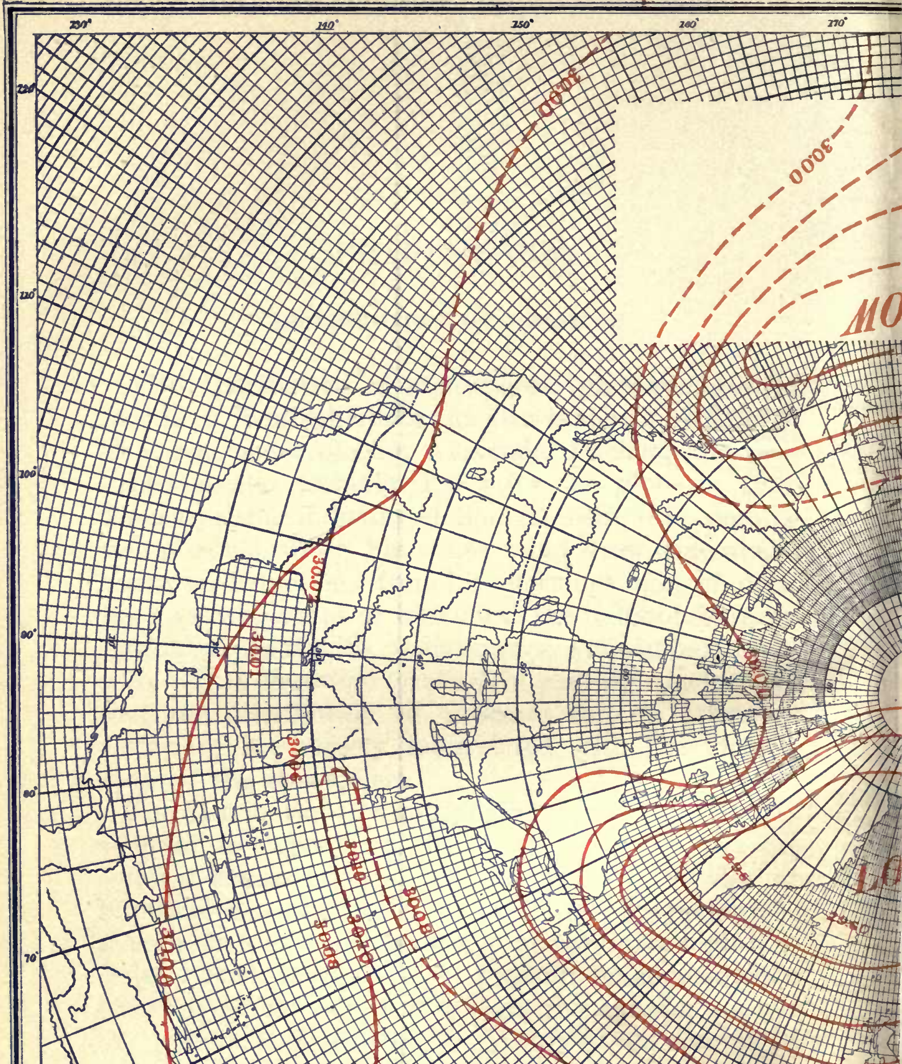
DISTRIBUTION OF PRESSURE.

THE distribution of atmospheric pressure over the Northern Hemisphere for the year is shown by Chart I. The great meteorologist, Alexander Buchan, first published similar isobaric charts for the globe in 1869. The surprising industry of Buchan made this compilation possible, while his acute mind drew general and accurate deductions from his enormous mass of data, the most important of which was the indissoluble association of winds with variations of atmospheric pressure. This discovery resulted in proving conclusively that the distribution of pressure and its attendant variations are closely interrelated with the temperature of the atmosphere.

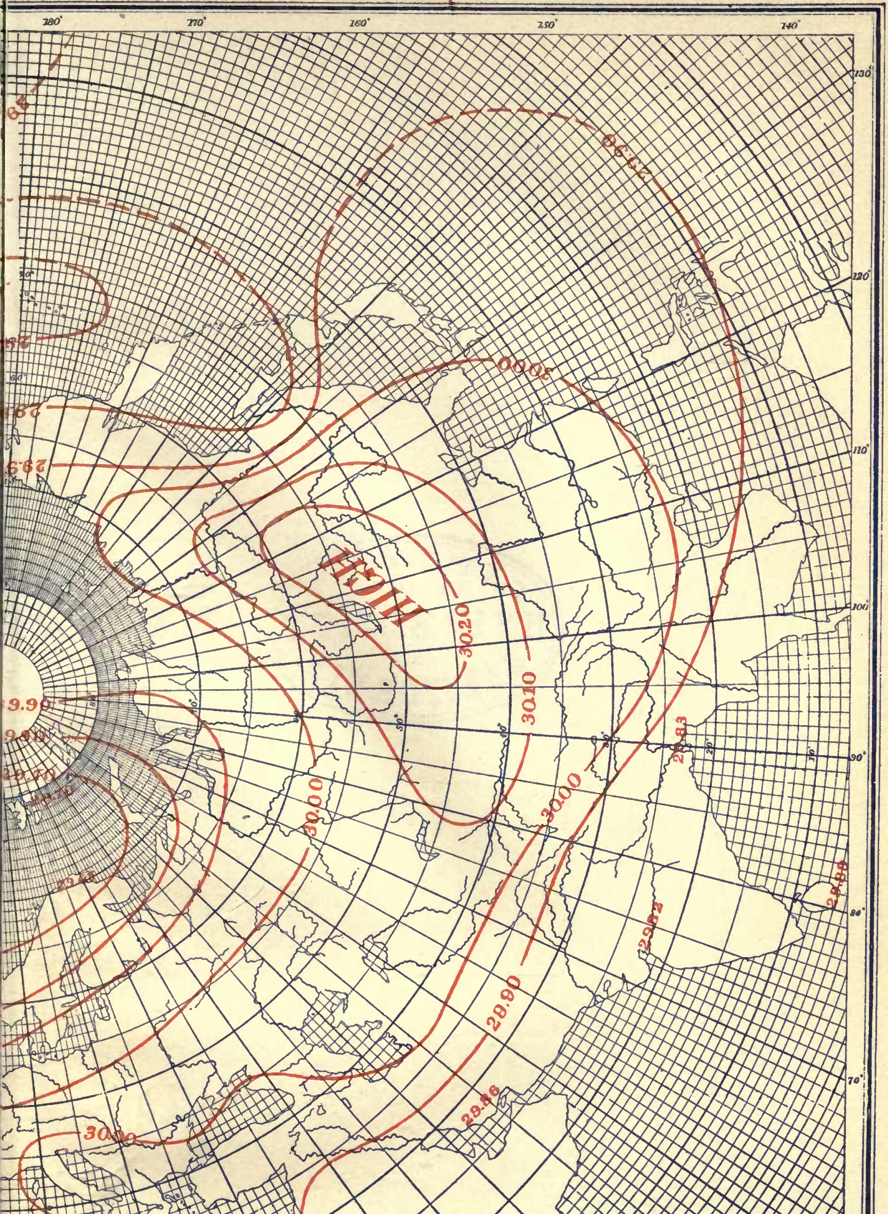
The distribution of atmospheric pressure is generally asserted to depend on the superheated air near the equator expanding and rising vertically, so that at higher levels—say 10,000 to 15,000 feet—the pressure is greater than at a corresponding elevation in high latitudes. Such inequalities of pressure must result in a tendency of the air to flow from the equator toward the poles. It is further set forth that, on account of the spherical shape of the earth, the air is crowded, as the meridians converge, into narrow channels, and finally forced down to the earth near the 30th parallel, where calms and high pressures ensue.

The author believes that to these causes must be added another, perhaps of much minor importance,

Mean Annual Atmospheric Pressur



over the Northern Hemisphere.



the effect of enormous masses of cold dense air, which, moving from high into middle latitudes, must necessarily tend to facilitate the movement of the upper air currents poleward.

Whatever simple principle underlies the primary movement of the atmosphere, it is necessarily interfered with and modified by complications arising not only from areas superheated in some instances, or chilled intensely by radiation in others, but also from the configuration of the earth in cases of immense mountain ranges, as the Himalaya, Caucasus, Andes, and Rocky Mountains; sandy deserts, such as the Sahara and Gobi, or by great interior basins, as in the United States.

Professor Mohn has plainly set forth in his admirable book* that the barometer is high (1) when the air is cold; (2) when the air is dry; (3) when an upper current sets toward an area; also that the barometer is low (1) when the lower strata of air are heated; (2) when the air is damp; (3) when the air has an upward movement.

Buys Ballot's law, which will be referred to later, shows the relation of wind to pressure, so that if the distribution of atmospheric pressure is known, the direction of the wind, which arises from differences of pressure, can be told, and *vice versa*.

The annual pressure is shown by Chart I. for the Northern Hemisphere; it rests, as do all such maps, on Buchan's early work, yet material changes have been made from original data of late years. The lines of mean pressure over the Atlantic Ocean have been drawn from international observations, 1881–83, inclusive, and in consequence the lines are less hypothetical

* Grundzüge der Meteorologie.

than usual, while those for the United States are from means of fifteen years' observations.

All the isobars on Chart No. I. are drawn from observations reduced to the level of the sea, but since the mean annual temperature is used as the *temperature argument* in such reduction, they are approximatively correct.

It will be observed that there are two areas of high pressure. One, at or above 30.1 inches, in the middle latitudes—extending as a band between the 20th and 40th parallels, from the Atlantic coast of the United States eastward to the shores of North Africa and Portugal—is quite permanent throughout the year, while the other, in the interior of Asia, with a mean pressure above 30.2 inches, owes its prominence to the very high winter pressures. There are three areas of low pressure, the most important of which exists in the vicinity of Iceland, about 29.6, while secondary minima are found in the Aleutian Archipelago slightly below 29.7, and in India about 29.8 inches.

It is doubtless true that there are regular and periodic changes in the atmospheric pressure from month to month, which are more or less masked by great accidental atmospheric variations attendant upon storms. These changes are called the annual fluctuation. By joining the tops of lines of different heights, representing the mean monthly heights of the barometer at any particular place, we have a curve showing the annual fluctuation of the pressure at that place.

The annual fluctuations of atmospheric pressure may be classified under two grand divisions or types, the first of which is expressed by a curve with a single inflection, while the last is in the form of a curve with two inflections or bends. The single inflection curve fluctuations are most general, while the double inflection curve in the Northern Hemisphere obtains in the polar or sub-polar regions, in Europe, Northern Africa, and over a part of the Atlantic Ocean. These annual atmospheric waves, with their crests and troughs, must move over the Northern Hemisphere somewhat in the same manner as the waves of high pressure, treated of later as cold waves, move throughout the winter months from the interior of the American Continent to the Atlantic seaboard. Doubtless, too, one simple law dependent to a greater or less extent on the relative positions of the earth and sun underlies this annual fluctuation. But barometric data now available has not yet been sufficiently analyzed to permit any simple expression of this law.

This annual fluctuation of the atmospheric pressure is a difficult problem, which has not been fully solved for the entire Northern Hemisphere. Personal investigations by the author show it to be more than probable that the maximum pressure occurs for the year over British America and part of Greenland in April, and that it moves slowly southeastward, covering Iceland, Norway, and Sweden, and the northern portion of the British Isles in May. The movement of this air farther southward across Europe and Africa is marked by a secondary maximum in June and July, while the maximum for Central Africa apparently occurs in August. This indicates that a part of these maxima pressures are due to a movement southeastward of cold air, chilled by the radiation of the long polar night of high latitudes. A secondary maximum in November covers the greater part of the Arctic circle, whence, the air moving southward, gives a primary maximum over Europe and the greater portion of India in December. The rest of Asia has a well-marked maximum in January and February, during which month the greatest pressure also obtains over the greater part of the United States, Northern Africa, and the Atlantic Ocean. The principal minimum occurs over Asia in July, excepting in the greater part of India, where it obtains in June. The principal minimum of April covers the United States, the Atlantic Ocean, and the Mediterranean Sea, and adjacent regions between the 30th and 40th parallels of latitude.

The curve showing the annual oscillations at Fort Conger coincides closely and regularly with the observations of the many expeditions in Arctic America since the commencement of this century. This marked double oscillation doubtless obtains annually at the north geographical pole, and hence is styled the polar type. A principal maximum in April gives way rapidly to the primary minimum in July, followed by a well-marked and complete secondary wave, the crest of which appears in November and the trough in January. A second type, called the American, a single annual curve, obtains in America and in parts of Europe and over the Mediterranean, where, however, it is more or less modified by the grand polar type. In the American type the single maximum of January rapidly gives way to a strongly marked depression in April, its recovery to the January maximum being slow but substantially uninterrupted.

The third type is called the Asiatic, and, like the American, consists of a single annual wave. The crest covers India and the valley of the Yenisei in December, but it is not simultaneous for all Asia, as the wave moves eastward, reaching the Pacific coast and the extreme southeastern part of Asia in February. The minimum pressure of the Asiatic type obtains in July for the greater part of that continent, although in Southern India it prevails a month earlier.

The observations at Honolulu, Hawaii, in connection with those of the Aleutian Archipelago, seem to indicate a fourth type. In this type, also a single wave, the June or July maximum wanes steadily to a January minimum over those portions of the North Pacific Ocean where it is not complicated by the advance of the Asiatic wave eastward in February. While the maximum of the Atlantic occurs generally in July, as on the Pacific, yet its maximum in middle latitudes, as shown by Bermuda and Delgada, obtains in April, as in the United States, and the influence of the polar secondary wave appears at both stations in the tendency to a secondary curve, with minimum in October and maximum in February.

While the movements of the atmospheric pressure from month to month, as here outlined, appear to be borne out by the international simultaneous observations for the past ten years, yet it must be admitted that more observations, especially in lower latitudes and over the Pacific Ocean, are necessary to determine how far these changes are regular and periodic. As bearing out the views here expressed—see Fig. No. 17—are presented typical curves of atmospheric pressure from observations reduced for temperature of barometer and instrumental error only, so that the phenomena can be studied with reference to the actual changes of pressure, and not with reference to the imaginary height, as found by reduction to the sea level, especially an important consideration where the elevation of the station is great.

As typical annual Asiatic curves of atmospheric pressure, there appears, in Fig. No. 17, those of Pekin, on the coast of China, Yeniseisk, in the interior of Siberia, and Agra in the interior of India. These are curves of great ranges, with a single inflection, with their maxi-

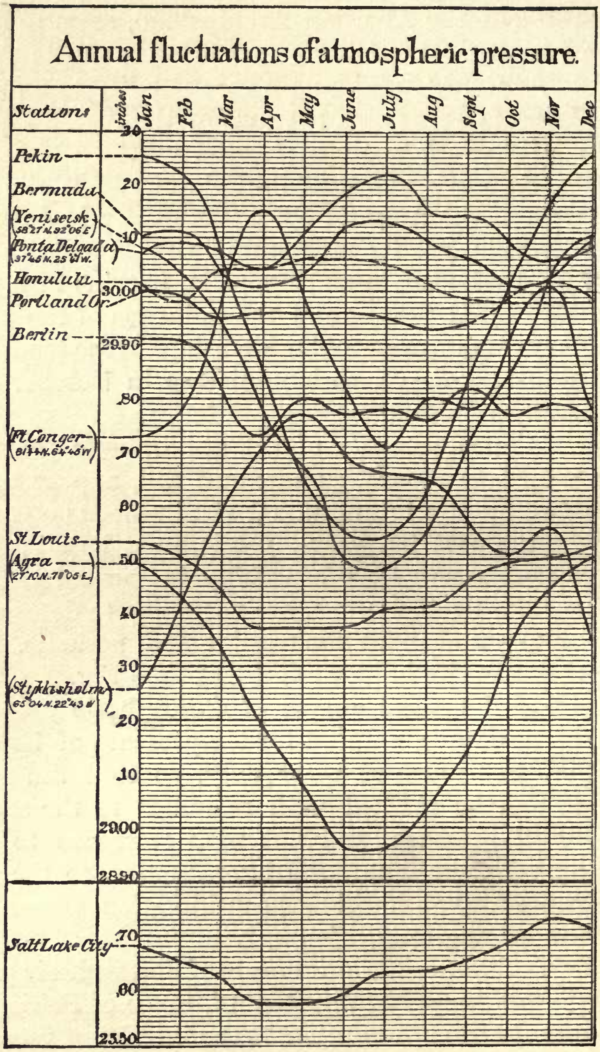

Annual fluctuations of atmospheric pressure.
Stations
inches
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Pekin
Bermuda
Yeniseisk
58°27'N. 92°06'E.
Ponta Delgada
37°45'N. 25°41'W.
Honululu
Portland Or.
Berlin
Ft Conger
St Louis
Agra
27°10'N. 78°05'E.
Stykkisholm
65°04'N. 22°43'W.
Salt Lake City
30
20
10
30.00
29.90
.80
.70
60
.50
40
30
20
.10
29.00
28.90
.70
.60
25.50

FIG. 17.

mum in January and their minimum in June and July. The curves of Portland, Ore., St. Louis, Mo., and Salt Lake City, Utah, are also curves with single bends, with their maxima in January and their minima in April, except at Portland, where it occurs in August. The curve at Honolulu, Hawaiian Islands, is a single wave, with its minimum phase in February and its maximum in May or June. The typical Arctic curves —with double inflections—are those of Fort Conger and Stykkisholm, the pressure rising from the primary minimum in January to the primary maximum in April or May. At Fort Conger a secondary minimum in July is followed by a very well-marked maximum in November, but at Stykkisholm the secondary minimum is delayed until October, and the November maximum, while well defined, is not as prominent as that of Fort Conger. The Ponta Delgada and Bermuda are typical Atlantic curves, with the primary minimum in April and the primary maximum in July, followed by a secondary wave, with its trough in November and its crest in February. At Berlin the wave is also double, falling from its primary maximum in January to its primary minimum in April. The irregular curve during the rest of the year shows a secondary maximum in September and minimum in December.

Over the United States the *actual** atmospheric pressure, as shown by the mean of fifteen years' observations, is greatest in January, in which month the maximum is reached from the entire Rocky Mountain slope eastward to the Atlantic coast, except over a portion of the lake region. The most important departure from this is over the immediate Rocky Moun-

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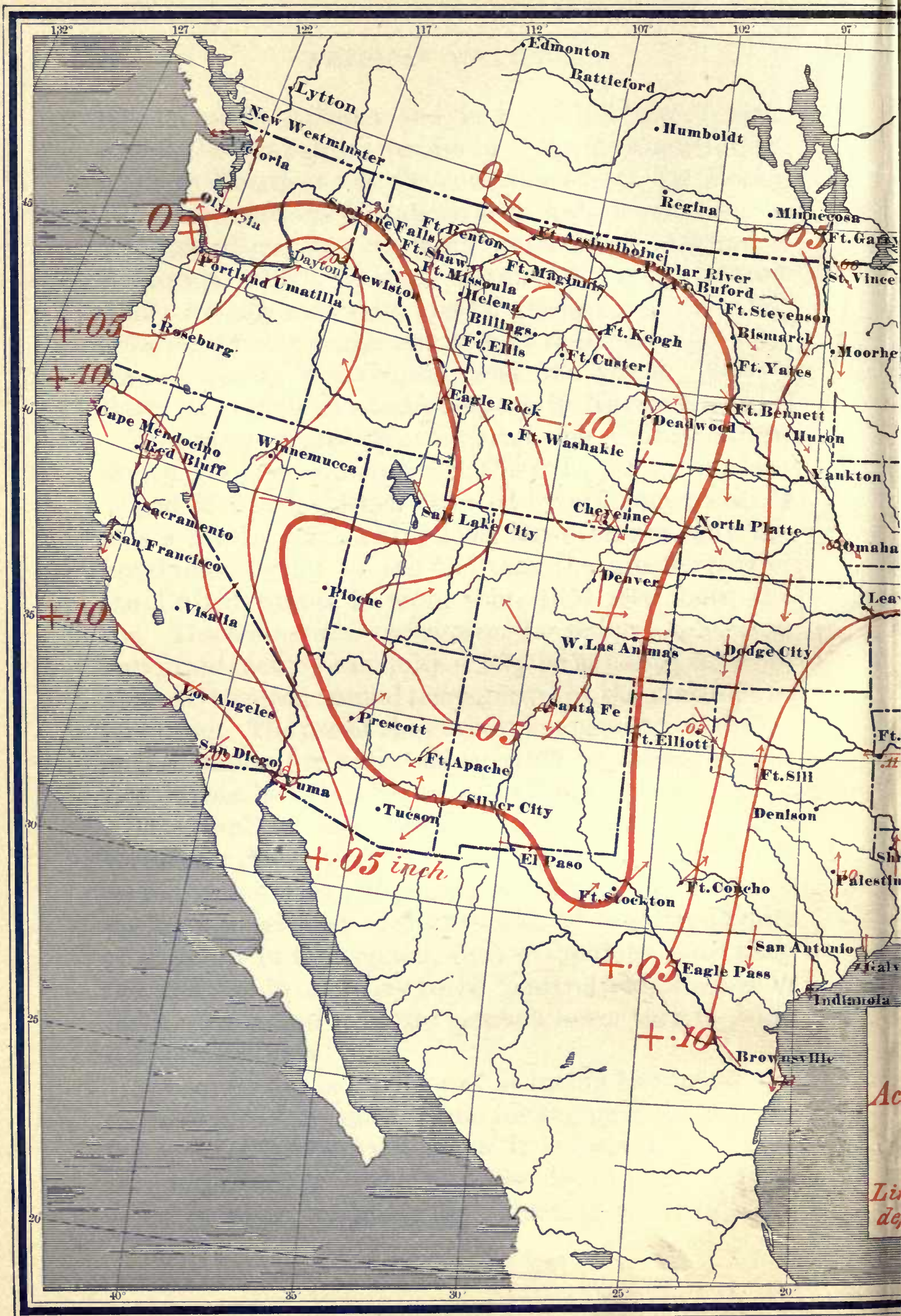
* By the *actual* is meant the recorded pressure, reduced for temperature of the barometer, etc., but not to the sea level or any other plane.

tain range, in Arizona and in a part of New Mexico, where the maximum occurs in July or August. Indeed, so divergent are the conditions over the Rocky Mountain stations (all above 4000 feet) from the general conditions, that the minimum obtains in January. California, with a January maximum throughout its whole extent, shows its special climatic condition by differing from the adjacent regions to its north or east, since Oregon, Washington, and the Great Interior Basin have their greatest pressures in November.

The mean yearly pressure over the United States, shown in a general manner on Chart I., ranges between 30 and 30.1 inches when reduced by ordinary methods to sea level. Such reductions, however, are only approximate, owing to the fact that the greater part of the United States is more than 1500 feet above the sea. The *temperature argument* for reduction—a very important factor—can quite safely be assumed to be the same as the mean annual temperature of the place of observation. The use of the current temperature of the air at the station for reducing monthly or daily observations to sea level has led to grave errors.

The result of this—the current method of reducing barometer observations at high stations in the plateau region of the Rocky Mountains to the *level of the sea*—has been to give an erroneous idea of the *actual* state of pressure in that region, such reductions indicating the pressure in January to be relatively high when in reality the *actual* pressure is much lower than at other times of the year.

The necessity is obvious of reducing barometer observations to a common plane for the purpose of making weather predictions, where it is essential to know the gradients of pressure or difference in pressure from place to place, which is the actuating cause or bears



Edmonton
Battleford
Lytton
New Westminster
Victoria
Humboldt
Regina
Minnecosa
Ft. Garry
St. Vincent
Olympia
Spokane Falls
Ft. Benton
Ft. Shaw
Ft. Assinniboine
Poplar River
Ft. Buford
Ft. Missoula
Ft. Maginnis
Helena
Dayton
Lewiston
Portland
Umatilla
Ft. Stevenson
Bismarck
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Ft. Yates
Moorhead
Roseburg
Eagle Rock
Ft. Washakie
Deadwood
Ft. Bennett
Huron
Cape Mendocino
Red Bluff
Winnemucca
Yankton
Sacramento
Salt Lake City
Cheyenne
North Platte
Omaha
San Francisco
Denver
Visalia
Pioche
W. Las Animas
Dodge City
Los Angeles
Santa Fe
Prescott
Ft. Elliott
Ft. Sill
San Diego
Ft. Apache
Yuma
Tucson
Silver City
Denison
El Paso
Ft. Stockton
Ft. Concho
Palestine
San Antonio
Eagle Pass
Indianola
Brownsville
0
+·05
+·10
−·10
−·05
+·05 inch
+·10

revailing Winds
and
al Atmospheric Pressure
for
January
show in English inches
tures from annual mean.
+·05 inch
+·05
+·10
Anticosti
Father Pt.
Chatham
Sidney
Quebec
Halifax
Eastport
Yarmouth
Rockliffe
Montreal
Burlington
Mt. Washington
Portland
Boston
Provincetown
New Shoreham
Prince Arthur's Landing
Duluth
Marquette
Mackinaw City
Parry Sound
Escanaba
Alpena
Sangeen
Toronto
Kingston
Oswego
Buffalo
Albany
La Crosse
Grand Haven
Port Huron
Milwaukee
Detroit
Erie
Dubuque
Chicago
Toledo
Williamsport
New Haven
New York
Sandy Hook
Barnegat
Atlantic City
Moines
Davenport
Sandusky
Cleveland
Pittsburgh
Philadelphia
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Norfolk
Cape Henry
Lynchburg
Kittyhawk
Cairo
Hatteras
Nashville
Knoxville
Charlotte
Chattanooga
Memphis
Ft. Macon
Wilmington
Smithville
Little Rock
Starkville
Atlanta
Augusta
Charleston
Vicksburg
Savannah
Montgomery
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba

an intimate relation to the motion of the air. But when the barometer is reduced to sea level with a view of representing the average condition of pressure for that region, and of proving a great increase of pressure and a consequent accumulation of air in winter, it is certainly misleading, since in reality there is a diminution of the amount of air present.

It results in representing, from month to month, that the atmospheric pressure, at stations covering an area of several hundred thousand square miles, is increasing, when it is actually decreasing.

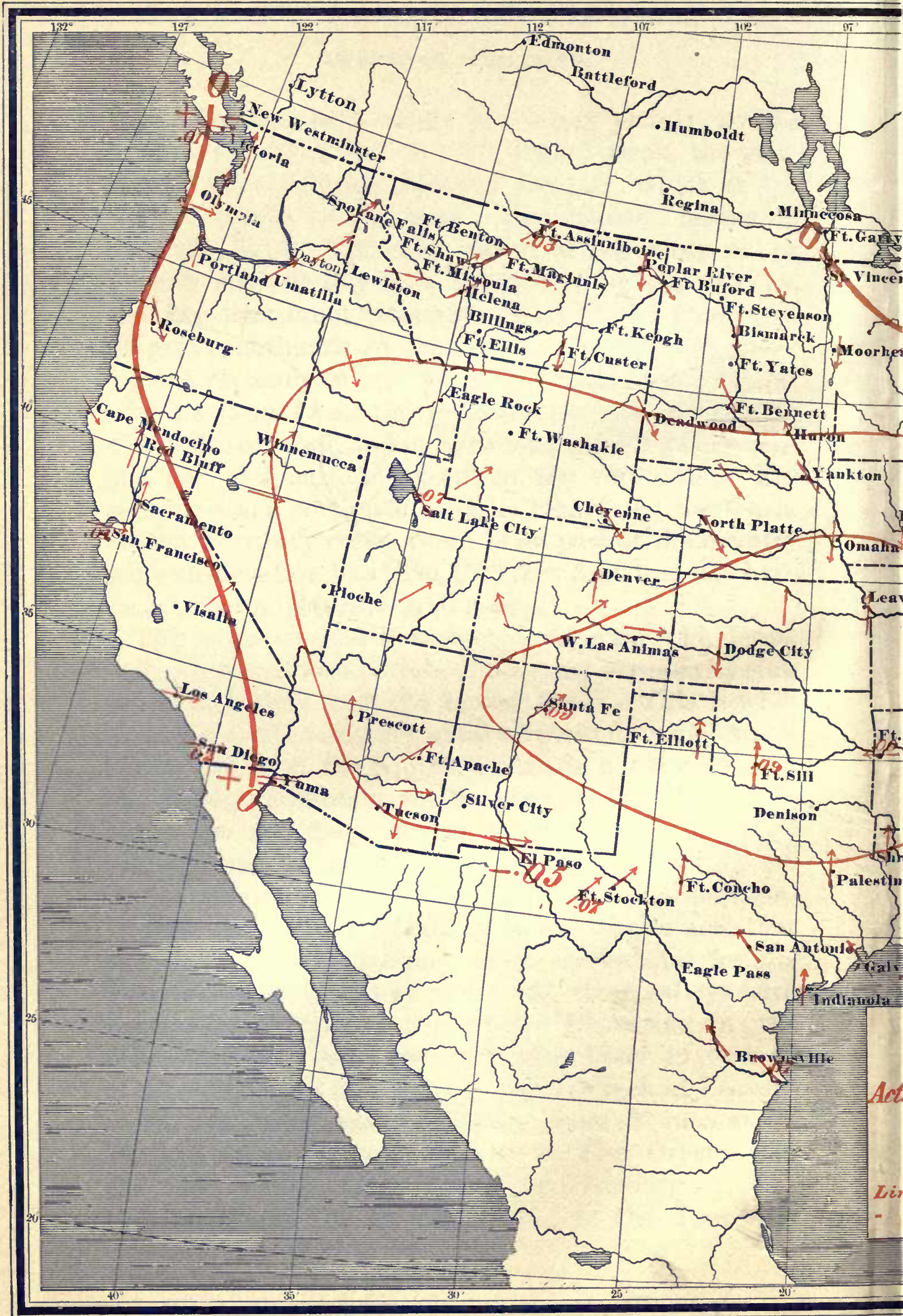
At Mount Washington, 6279 feet above sea level, the mean actual barometer in January is half an inch less than in July, while at sea level in the vicinity the January pressure is higher than that for July. This result is due to the lower average temperature of January contracting the great body of the air, so that more of it is brought below the summit of the mountain. But if there were a great plain in the vicinity of the mountain at the same height, it would obviously be improper, in a discussion of its climatic peculiarities, to analyze its pressures for that purpose from the point of view of their reduction to the sea level, yet such method of treatment has heretofore obtained for the high plateau regions in the western part of the United States.

The author has preferred to depart from such a method of representation in treating the monthly mean pressures over the United States for January and April —the months which show, for the greatest area, the maximum and minimum pressures. Charts II. and III. are based entirely on the actual means—*i.e.*, only reduced for the temperature of the barometer to 32°, the departures of January and April from the annual means of the actual readings being used.

The January map, Chart II., shows plainly, by the method of departure from the annual mean, the pressure of the atmosphere during January, which is the coldest month of the year. The January minimum over the Rocky Mountain region is the more to be noticed since it has been insisted on by some writers that the maximum pressures occur in the interior of all great continents in January, or the winter season.

Such certainly is not the case in the United States, with its January maximum almost unbroken along its 4000 miles of coast, and no such maximum between 100° and 120° of longitude except at the very coast. Excepting over a portion of the lake region and the Washington Territory coast, there is no part of the country with an elevation less than 1500 feet that does not have its maximum pressure in January.

This is what might be expected, since the cold, dense, and contracted lower strata of air must necessarily sink down and thus seek the lowest levels. This is what occurs, and the cold, dry areas of pressure which move southward into the United States do not remain over the Rocky Mountain region, since these dense, cold strata are not deep enough to reach up to the high plateaus nor to overflow the mountain crests and fill up the great interior basin of Idaho, Utah, and Nevada. In this connection it is further interesting to note that the excess of the January mean above that for the year increases regularly along the river valleys with decreasing elevation; the excess increasing in the Missouri Valley from zero at Poplar River to .04 inch at Bismarck, .08 at Yankton, and .10 inch at Leavenworth; in the Mississippi Valley, from .07 inch at St. Paul to .08 at St. Louis and .10 at New Orleans; in the Ohio Valley, from .05 inch at Pittsburg to .07 at Cincinnati and .08 at Louisville; in the Tennessee



132°
127°
122°
117°
112°
107°
102°
97°
45
40
35
30
25
20
Edmonton
Battleford
Humboldt
Lytton
New Westminster
Victoria
Regina
Minnecosa
Olympia
Spokane Falls
Ft. Benton
Ft. Assiniboine
Ft. Shaw
Ft. Maginnis
Poplar River
Ft. Buford
Dayton
Lewiston
Ft. Missoula
Helena
Portland
Umatilla
Ft. Stevenson
Billings
Ft. Keogh
Bismarck
Roseburg
Ft. Ellis
Ft. Custer
Ft. Yates
Eagle Rock
Ft. Bennett
Deadwood
Huron
Cape Mendocino
Ft. Washakie
Red Bluff
Winnemucca
Yankton
Cheyenne
Salt Lake City
North Platte
Sacramento
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Santa Fe
Los Angeles
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Denison
Tucson
El Paso
Ft. Concho
Ft. Stockton
San Antonio
Eagle Pass
Indianola
Brownsville
40°
35°
30°
25°
20°

Prevailing Winds
and
Atmospheric Pressure
for
April
show in English inches,
from annual mean.
.05 inch
.08
.06
.05
Prince Arthur's Landing
Duluth
Marquette
Mackinaw City
Escanaba
Alpena
Paul
La Crosse
Grand Haven
Port Huron
Milwaukee
Detroit
Dubuque
Chicago
Toledo
Moines
Davenport
Sandusky
Cleveland
Erie
Keokuk
Champaign
Indianapolis
Columbus
Cincinnati
Springfield
St. Louis
Louisville
Cairo
Nashville
Chattanooga
Knoxville
Charlotte
Memphis
Little Rock
Starkville
Atlanta
Augusta
Vicksburg
Montgomery
New Orleans
Pensacola
Port Eads
Jacksonville
Cedar Keys
Punta Rassa
Key West
Havana
Santiago de Cuba
Savannah
Charleston
Smithville
Wilmington
Hatteras
Kittyhawk
Cape Henry
Norfolk
Lynchburg
WASHINGTON
Baltimore
Philadelphia
Pittsburgh
Williamsport
New York
New Haven
Albany
Buffalo
Oswego
Kingston
Sangeen
Toronto
Parry Sound
Rockliffe
Montreal
Quebec
Burlington
Mt. Washington
Portland
Boston
Provincetown
New Shoreham
Sandy Hook
Barnegat
Atlantic City
Del. Breakwater
Eastport
Halifax
Yarmouth
Father Pt.
Chatham
Sidney
Anticosti

Valley, from .06 inch at Knoxville to .08 at Chattanooga and .09 at the junction of the river with the Ohio. This is clearly the result of the cold air settling down in the river valleys, thus increasing the density of the lower strata of the atmosphere. Over the whole of the region between the 102d and 115th meridians, including the Rocky Mountains and parts of the plateau region, the pressure is decidedly lessened, and over the whole of this region the pressure decreases from December to January, after which month there is an increase over most of the region mentioned until the maximum in July. The greatest excess east of the Rocky Mountains is found in the southeastern half of the Atlantic States, toward which quarter the cold areas of air flowing out of British America tend, as is shown by the prevailing north and northwest winds. It is interesting to note that the line of no change is substantially coincident with the contour elevation lines for 3000 feet, which elevation, it is possible, would prove satisfactory, as a plane, to reduce at least the winter observations of the barometer.

The month of minimum pressure over the United States—see Chart III.—is not as satisfactorily and sharply defined as is that of the maximum pressure. Over one third of the country the lowest pressure occurs during the month of April, and in other contiguous sections, equal in area, during May and June. It is possible that the means derived from fifteen years' observations are not sufficient to clearly settle this question, and that a longer series would show that May is the month of minimum pressure, except along the Pacific and South Atlantic coasts and over the Rocky Mountain region, including the Interior Basin. The minimum for California and Oregon, from fifteen years' observations, is very well marked for August, during which month the pressure is also the lowest on the Atlantic coast south of the 35th parallel. A considerable portion of the immediate Rocky Mountain region has its lowest pressures during January, the month when it is theoretically claimed it should be the highest.

Variations in the atmospheric pressure are *periodical* (that is, recur at regular intervals) or *accidental* (that is, result from influence of the extraordinary and unusual disturbances of the local atmospheric conditions). The *daily variation* is the most marked of the periodic variations, and it assumes the greatest regularity, as well as the greatest amplitude, near the equator, and is the least marked in very high latitudes. At Calcutta, according to Buchan, the primary maximum occurs at 9 A.M. and the primary minimum at 4.30 P.M., followed by a secondary phase at 12.30 A.M. and 3.30 A.M. The amplitude varies from .117 at Calcutta, in 22 N., to .010 inch at Fort Conger, in 82 N.

Various theories have been advanced to explain the cause of the diurnal oscillation of the barometer, none of which have been completely satisfactory. The diurnal changes in temperature and in the quantity of aqueous vapor present in the air are presumed to exercise the greatest influence. The idea was formerly advanced that the daily barometric variation entirely disappeared within the Arctic circle, where no alternation of day and night occurred. Such opinion is, however, disproved by the various observations made within the Arctic circle; notably those by international polar expeditions at Spitzbergen, Point Barrow, and Fort Conger (see Fig. 18). The comparison of the Arctic curves by the author showed the great probability that at least one component of the diurnal fluctuation depends upon other causes than the alternation

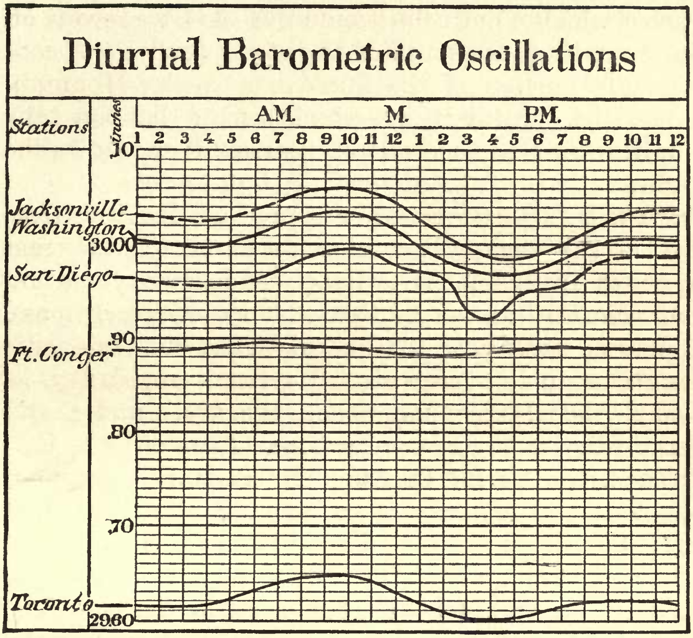


FIG. 18.

of day and night, and that this wave does not always follow the sun in the rotary movement of the earth.

In charting the hourly oscillations from a number of Arctic stations, it was found that on maps with reference to local time the curves were thoroughly discordant. When charted on simultaneous time, for fifteen out of twenty-four hours the values of the departures, either plus or minus, are in accord, but when charted on local time, at no single hour do the values have the same sign at all stations.

Observations have not been sufficiently numerous to determine accurately the diurnal variation in the barometer for the United States, except at a few scattered stations. For the country generally it may be said, however, that the amplitude ranges from .040 to at least .100 inch.

It is in general a correct statement that the daily amplitude of the barometer decreases in the United States with increase of latitude, but to this decrease there are important and well-marked interruptions. East of the Rocky Mountains the amplitude increases to about parallel 31° N., whence the decrease is regular and constant to the northward. From Georgia and Tennessee westward to Central Texas there is a large area of country over which the range appears to be considerably larger than that to the north and south. For instance, the range increases from .076 inch at Jacksonville to .101 at Augusta; from .090 at Pensacola to .099 at Montgomery; from .090 at New Orleans to .104 at Shreveport, and .093 at Memphis and Nashville; and from .073 inch at Brownsville to .090 at San Antonio, and .110 at Fort Stockton. These values have not been determined, however, with very great accuracy, but observations prove quite conclusively that over this section, for a considerable distance inward from the Gulf coast, the amplitude increases to the northward. A portion of this irregularity may be attributed to the distance from the sea or great lakes, as the amplitude, possibly a result of a continental climate, is .100 at Montgomery, Ala., .104 at Fort Stockton, Tex., and .078 at Leavenworth, Kan., and Winnemucca, Nev. Other causes, however, than distance from the sea alone must obtain, since among the smallest amplitudes of the United States are those of Dakota and Northwestern Minnesota—.023 at St. Vincent and .040 at Bismarck. The smallest known variation elsewhere in the United States is .027 inch at Thunder Bay Id., Mich.

The amplitude over Nevada, Idaho, and other portions of the Interior Basin and plateau districts of the United States, also increases from the great lakes westward and from the Pacific Ocean to the eastward.

Fig. No. 17 shows, charted on local time, the diurnal curve for various stations in the United States. The curves for Washington and Toronto are much better determined than the others. The Fort Conger curve is added to show that the diurnal variation obtains near the North Pole.

Next in order comes the monthly variation or range. The *mean monthly* range of the barometer in the United States increases quite regularly with latitude, and decreases slightly and somewhat irregularly with increasing longitude. The ranges vary from 0.35 inch at Key West to 1.16 at Eastport, on the Atlantic coast; from 0.36 inch at San Diego to 0.78 at Tatoosh Island, on the Pacific coast; and from 0.55 inch at Brownsville to 1.02 at St. Vincent, on the 97th meridian.

The range is least for the month of July almost without exception throughout the country; but while the greatest mean range occurs in January as a rule, yet at occasional points the maximum obtains in December or February.

The annual range in the United States rarely exceeds one inch, except to the northward of the 40th parallel or along the immediate Atlantic coast. The annual range at Toronto, Canada, for forty-six years, is 1.65 inches, with an absolute range of 2.77 inches.

The absolute ranges are naturally connected with violent atmospheric disturbances, and the lowest barometer readings as a rule occur either in connection with the permanent areas of low pressure in the vicinity of Iceland in the Atlantic, or of the Aleutian Islands in the Pacific Ocean. At Unalaska, January

21st, 1879, a reading of 27.70 was noted, and at Stykkisholm 27.91 was recorded February 1st, 1877.

Even more remarkable readings have been noted in connection with the typhoons of the China Sea and the cyclonic storms of the Atlantic. On September 27th, 1880, the ship "Chateaubriand," in 22° N., 121° E., experienced a violent typhoon, during which the barometer sank in four hours from 29.64 to the unprecedented point of 27.04. Wind of force 12, from the northwest, was followed by a dead calm and then by south and southeast winds, force 12, thus showing that the vessel was in the centre of the typhoon.

The following interesting and unusually low and high barometer readings are recorded: 22° N., 121° E., near Grand Turk Island, 27.04, September 27th, 1880; Ochtertyre, Perthshire, Scotland, 27.33, January 26th, 1884; Onset Head, England, 27.45, December 8th, 1886; 28° N., 68° W., "Golden Fleece," 27.60, October 2d, 1880; 59° N., 24° W., 27.68, January 17th, 1879, September, 1880; Unalaska, 27.70, January 21st, 1879; 53° N., 25° W., "Austrian," 27.88, November 30th, 1878; Hainan Reefs, E., 27.88, October 16th, 1880; 29° N., 132° W., 27.88, October 2d, 1880; Stykkisholm, 27.91, February 1st, 1877; 41° N., 57° W., 28.00, October 29th, 1879; 38° N., 35° W., 28.02, October 8th, 1878; 49° N., 21° W., 28.08, April 1st, 1886; off Umqua, Ore., 28.20, January 9th, 1880; North Unst, 28.21, March 1st, 1880; 28° N., 88° W., 28.38, September 9th, 1882; Nagasaki, 28.50, August 4th, 1880; Halifax, 28.59, November 20th, 1879; Reunion, 28.62, March 20th, 1879; Mauritius, 28.62, March 21st, 1879; Kingston, Jamaica, 28.93, August 18th, 1880; Crooked Island Passage, 28.94, September 4th, 1882; Trinidad (*lowest*), 29.04, September 2d, 1878; Bermuda, 29.14, August 30th, 1880; N. W. Russia, 30.91, February

17th, 1880 ; Fort Conger, 31.00, March, 1883 ; "Jeannette," 31.09, 1880 ; Barnaul, 31.21, January 9th, 1877 ; Fort Assinaboine, 31.21, January 6th, 1886.

The absolute range for the United State varies from 1 to 2½ inches, increasing along the Atlantic and Pacific coasts with the latitude ; but, owing to the cyclonic disturbances prevalent in the Gulf of Mexico, they are greatest on the Gulf coast, decreasing northward for several hundred miles, and then gradually diminishing.

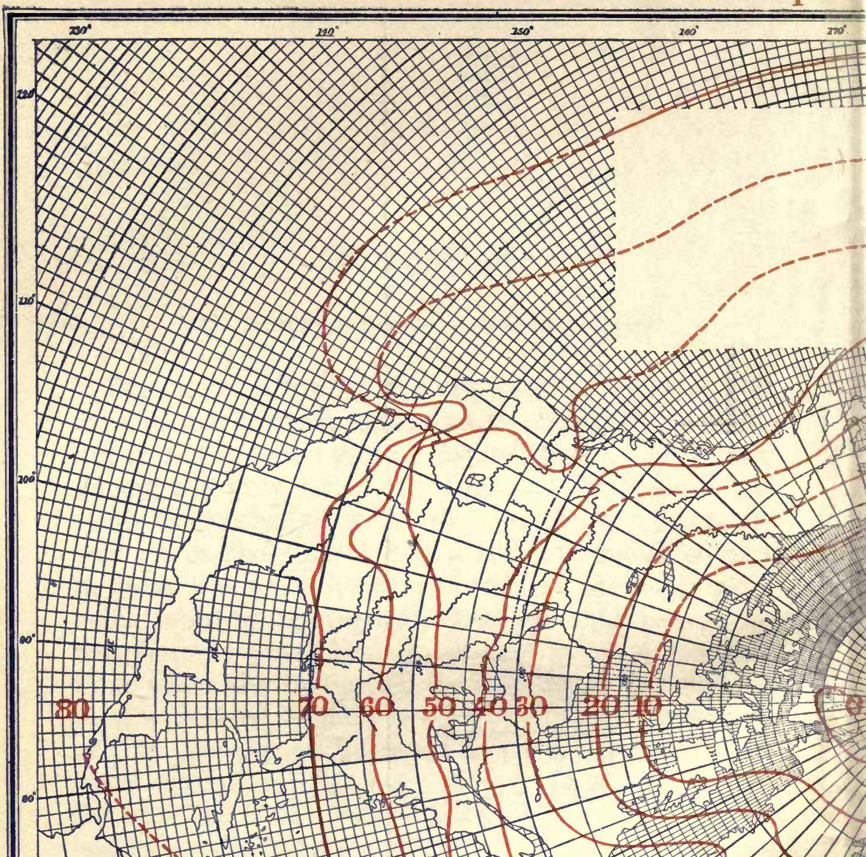
The following absolute ranges illustrate the United States generally in this respect : San Diego, Cal., 1.014 inches ; Olympia, Wash. Terr., 1.717 inches ; Key West, Fla., 1.176 inches ; New York, 2.201 inches ; Eastport, Me., 2.523 inches ; Brownsville, Tex., 1.896 inches ; Chicago, Ill., 1.775 inches, and St. Vincent, Minn., 1.786 inches.

CHAPTER IX.

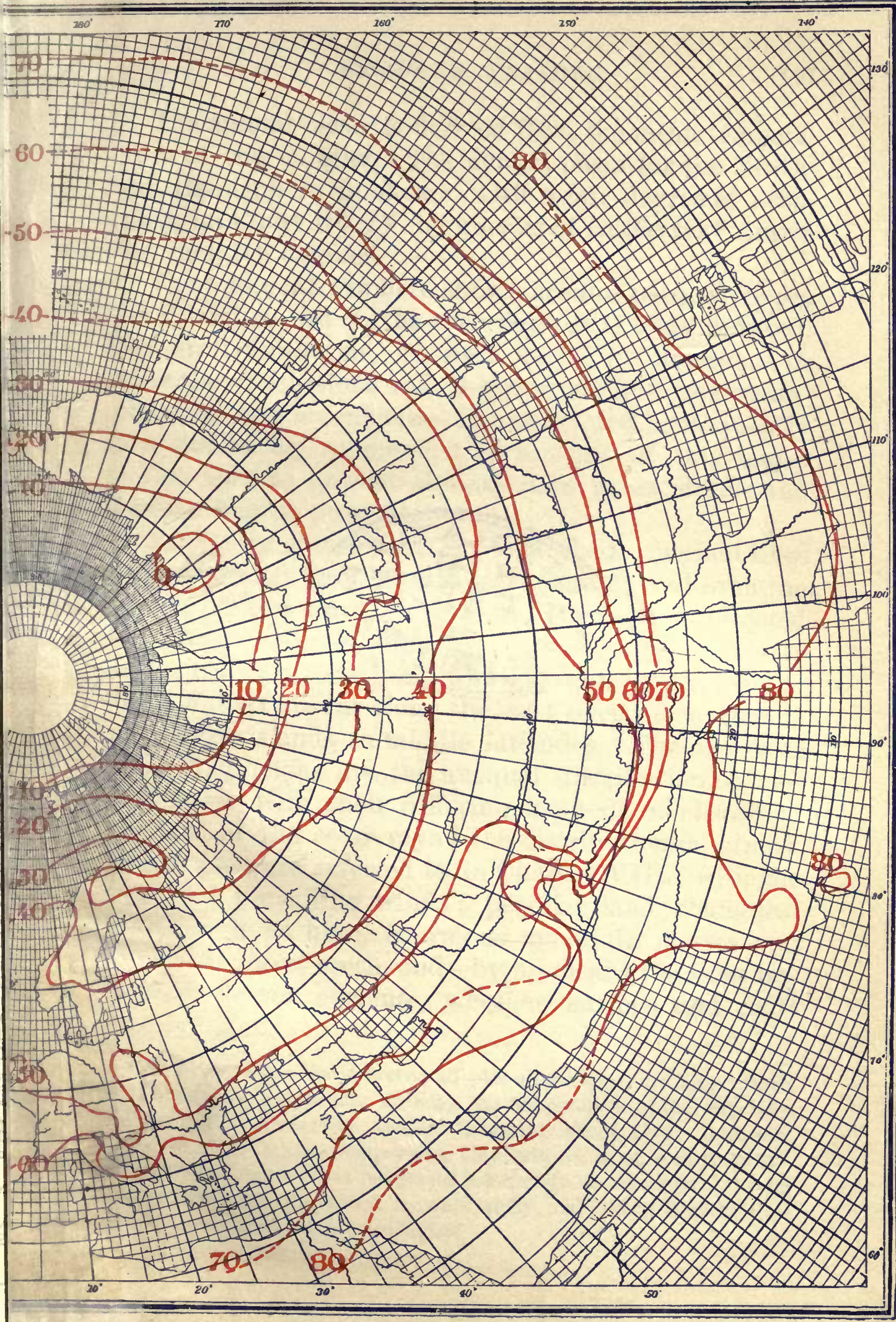
THE DISTRIBUTION OF TEMPERATURE.

THE temperature of the air results from the solar rays, as has been set forth, and the amount of heat depends, not so much on the varying distance of the sun during the year, as on the angle at which these rays strike the surface of the earth. The sun is most nearly vertical in the United States at the summer solstice in June, when the heating powers of the sun's rays, being more nearly vertical, have less thickness of atmosphere to pass through, so that it loses less heat than when the inclination is greater, as has already been explained in Chapter IV. The solar rays being of high power pass through the air with comparatively small loss of heat, and so affect most materially the temperature of the surface of the earth; thus producing effects which vary according to the character of the surface upon which the solar rays fall. The immediate surface of the earth and its vegetation having absorbed the heat of the solar rays, in turn radiates it toward space; but the character of the rays have changed, so that it becomes dark heat, and consequently its effect in changing the temperature of the atmosphere is very much greater than that wrought directly by the solar rays. In consequence of the varying changes in the inclination of the solar rays toward the earth, as well as a diminution in the hours of sunlight, the temperature of the earth changes from month to month.

Mean Annual Tempera



ure of the Northern Hemisphere.



The annual mean is derived from the mean temperature of the months. The annual mean for the Northern Hemisphere is shown, with a fair degree of accuracy, on Chart No. IV. by a series of *isotherms* * drawn for each ten degrees.

The temperatures here shown are not reduced to sea level, and so are not as accordant as if thus reduced. Sea-level isotherms, however useful for elaborate or scientific discussions and theories, are but representations, having no existence in nature, and consequently are not to be commended in a work of this scope, which aims to present climatic data in as simple and plain a way as possible.

A cursory glance discloses that the isothermal lines are not strictly parallel with the equator ; that even the belt of highest mean temperature is not equally bisected by that great circle, while the isotherms are irregularly and curiously distorted. The greatest inclinations to the parallels appear along the west coast of continents and large islands in middle latitudes. The causes of these distortions are the unequal distribution of land and water, with their differing methods of absorbing the heat of the solar rays ; the distribution of atmospheric pressure referred to in Chapter VIII., with the resulting prevailing winds ; peculiar land configurations, such as high, enormous mountain masses and extensive desert areas, and—by no means the least important—ocean currents, whether surface and drift

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* An *isotherm* is a line whereon all places have the same temperature. This method of graphically showing the temperature of the terrestrial globe was first extensively used by Humboldt about 1817. Isotherms take their name from the temperature they indicate, as an isotherm of 32°, 50°, etc. Isotherms, when mentioned indefinitely, are understood to refer to the mean temperature, but monthly, daily, and hourly isotherms are now in constant use by meteorologists.

from the wind, or permanent from vertical distribution of sea temperatures.

The mean temperature of the land in equatorial regions is higher than that of the ocean, but in higher latitudes reverse conditions obtain. The transfer of heat from the equator by wind and ocean currents tends to equalize the temperatures of different latitudes.

As bearing on the oceanic influence a brief allusion to the distribution of sea temperature is necessary.

The temperatures of both the surface and the depth of the Atlantic Ocean have been observed with great care during the past twenty years, so that enormous as is the expanse of water, yet a fairly accurate knowledge is now had from the equator to the 80th parallel. The sun's heat is not absorbed entirely by the surface water, but a considerable portion passes through the upper layer of the sea, so that the solar heat probably extends downward about five hundred feet. The temperature of the sea follows that of the air quite slowly, so that its daily *amplitude* is considerably less than that of the air. According to observations on the Atlantic seaboard of the United States, the sea and air throughout the year fluctuate to about the same extent from Key West to Southport, N. C. At Sandy Hook, however, the fluctuation of the temperature of the air, as determined from monthly means, is twenty-five per centum greater than that of the sea, while at Eastport the variation amounts to two hundred and forty per centum. The sea lags about half a month behind the air in its march of temperature from Key West to Southport, N. C., whence the retardation increases, amounting to one month at Sandy Hook, N. J., and to nearly two months at Eastport. The sea averages about one degree colder at Key West, 2.5° at Sandy Hook, and 6.5° at Eastport, Me.

The sea-water isotherms are much more regular than those of the air, but they are more open along the coast of Africa and Europe than that of America, so that with increasing latitude their trend changes from nearly east and west to northeast and southwest.

The annual temperature of the surface of the sea ranges from about 75° just north of the equator along the Gold Coast, to 28° in the Great Frozen Sea to the northward of Grinnell Land. The variation of mean temperature is thus about sixty per centum of that of the air, which ranges from —5° at Fort Conger to 84° at Massowah, Red Sea.

But below the point at which the sun's heat ceases to affect the sea the temperature conditions change most materially. At the bottom of the Great Frozen Sea the temperature is doubtless about the same as at the surface, and from that point it increases toward the equator from 28° to 37° at the greatest depths. At a plane of some 4000 feet below the surface the observations show an increase from 37° to 47°, the rise in the temperature being to the southward till the 30th parallel is reached, whence it decreases to about 40° under the equator. Along the European coast is a layer of warm water at 4000 feet, the temperature off the Mediterranean rising slightly above 50°.

The influence of the predominance of water is best illustrated by the isotherms of the British Isles, where the summer temperatures are lowered and the winter temperatures raised through this influence, which is re-enforced on the windward side by the prevailing winds. The only part of the United States where the climate is affected by the oceanic current is the immediate Pacific coast, where the mild and equable temperature results in part from the Japan current and the prevailing winds which have passed over its surface. It is evident that the temperature of the Pacific coast can be materially affected by this current only in an indirect way, by its keeping permanently at a comparatively high temperature the winds which pass over its surface. The effect of oceanic currents is most forcibly shown in the northeasterly projection of the isothermal curves along the coast of Northwestern Europe. These (considering the latitude) abnormally high temperatures in Great Britain are doubtless due in part to the oceanic circulation in that direction; but how and to what extent is a hotly disputed question. Dr. W. B. Carpenter maintained that this amelioration of the climate of Northwestern Europe is caused by the general oceanic circulation, and not by the Gulf Stream. The writer concurs with Dr. Carpenter in believing that the Gulf Stream, as such, disappears in the mid-Atlantic Ocean, but also believes that not enough weight has been given to the effect of the quite permanent and extensive barometric depression in the vicinity of Iceland, which brings in its circulatory system of air currents the prevailing southwest winds, most essential factors in the amelioration of British climate. It is significant that any marked displacement of this low area to the southeast results, as Buchan has plainly shown, in abnormally low temperatures for the British Isles, despite the Gulf Stream or the general oceanic currents. Moreover, it is an even question if the unequal distribution of barometric pressure, with its attendant changes above referred to, are not quite as important factors in producing the general oceanic circulation as is the vertical distribution of temperature set forth by Carpenter as the predominating influence.

The influence of mountains upon the distribution of temperature depends, in part, on their inducing the served) between these two places are nearly as striking in their variation, being 61° at San Francisco and

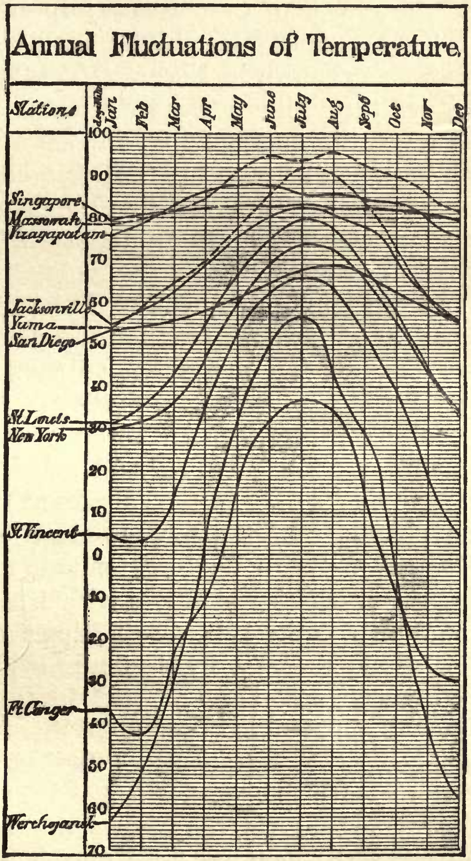


FIG. 19.

128° at St. Louis. These data illustrate in the most striking manner the difference between a continental climate and a marine climate; for the peculiar situation of San Francisco upon a peninsula causes its climate to be almost insular.

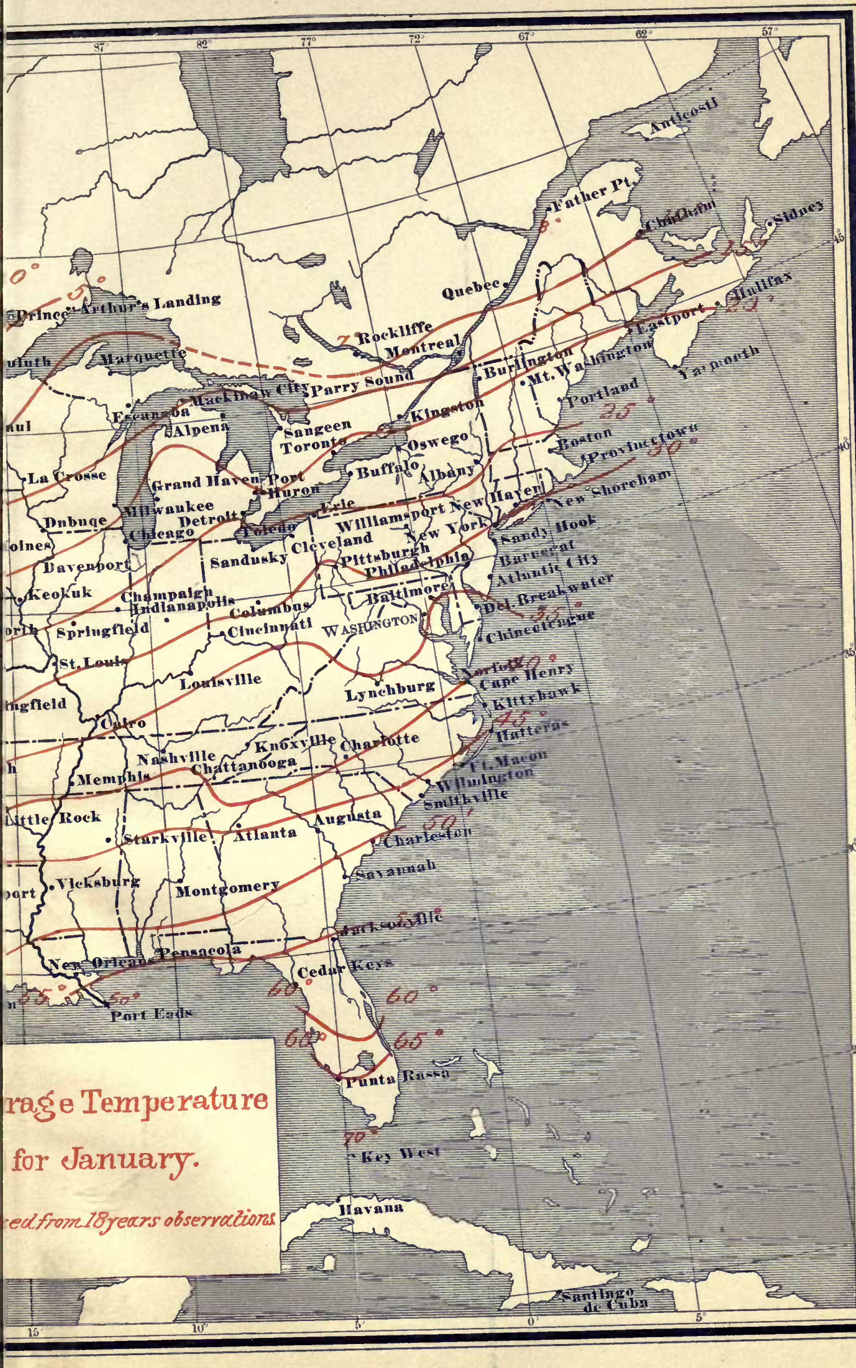
But the march of temperature or its distribution throughout the year is of the greatest importance, and this is most conveniently illustrated by plotting the monthly means, as shown in Fig. 19. This variability of temperature throughout the year has an absolute bearing on vegetation, animal life, and on all kindred phenomena in which mankind is vitally interested.

The amount of heat received by any place on the globe (with the intervening atmosphere through which the sun's rays pass) depends on the inclination of the solar ray and the length of the day. It follows, then, that the amount of heat received for any given month depends on the position of the sun, so that, as Blanford has set forth, the greatest quantity of solar heat near the equinox would fall at the equator, between May 1st and August 15th from 30° and 40° N. latitude, and for the six weeks nearest the solstice at the North Pole. The character of the surface—land or water, desert or forest—receiving the heat tends to materially modify the march of temperature, which in but few locations shows these theoretical conditions.

The effect of the greatest insolation is evident only on lands of considerable extent, and in the interior thereof. In "Vade Mecum," page 149, Blanford illustrates the temperature conditions of India by a chart for May (the month of greatest solar heat for that country), 1875, where the isotherms are concentric curves following the contour lines of the peninsula, and increasing from the sea until they exceed 95° in the interior.

Fig. 19 contains typical illustrations of the annual march of temperature in various parts of the Northern Hemisphere. The curve for Fort Conger, the station

Edmonton
Battleford
Lytton
Humboldt
New Westminster
Victoria
Regina
Minnecosa
Olympia
Spokane Falls
Ft. Benton
Ft. Assinniboine
Ft. Garry
Ft. Shaw
Ft. Maginnis
Poplar River
St. Vincent
Dayton
Lewiston
Ft. Missoula
Ft. Buford
Portland
Umatilla
Helena
Ft. Stevenson
Billings
Ft. Keogh
Bismarck
Moorhead
Roseburg
Ft. Ellis
Ft. Custer
Ft. Yates
Eagle Rock
Ft. Bennett
Deadwood
Huron
Cape Mendocino
Red Bluff
Ft. Washakie
Winnemucca
Yankton
Cheyenne
North Platte
Sacramento
Salt Lake City
Omaha
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Santa Fe
Los Angeles
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Denison
Tucson
El Paso
Ft. Stockton
Ft. Concho
San Antonio
Eagle Pass
Indianola
Brownsville



rage Temperature
for January.
ed from 18 years observations
Anticosti
Father Pt.
Sidney
Quebec
Halifax
Eastport
Yarmouth
Prince Arthur's Landing
Rockliffe
Montreal
Burlington
Mt. Washington
Portland
Marquette
Parry Sound
Kingston
Escanaba
Alpena
Saugeen
Toronto
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
New Haven
New Shoreham
Milwaukee
Detroit
Erie
Williamsport
New York
Sandy Hook
Dubuque
Chicago
Toledo
Cleveland
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Davenport
Sandusky
Baltimore
Del. Breakwater
Keokuk
Champaign
Indianapolis
Columbus
Cincinnati
WASHINGTON
Chincoteague
Springfield
St. Louis
Louisville
Lynchburg
Norfolk
Cape Henry
Kittyhawk
Cairo
Hatteras
Nashville
Knoxville
Charlotte
Chattanooga
Memphis
Ft. Macon
Wilmington
Smithville
Little Rock
Starkville
Atlanta
Augusta
Charleston
Vicksburg
Montgomery
Savannah
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba

having the lowest known mean temperature of the globe (−5°), might be expected, from its very high latitude, with four and a half months of sunless winter and the same duration of continuous summer sunlight, to show more forcibly the results of summer insolation and winter radiation. It is, however, located on a land of limited extent, contiguous to enormous ice-capped lands and to broad straits and seas which furnish enough aqueous vapor to materially modify the march of temperature. The curves of Werchojansk, Siberia (67° N. lat.), and St. Vincent, Minn. (49° N. lat.), illustrate for Asia and America, respectively, the extent to which winter radiation can chill the dry air of stations situated in the interior of great continents, and how great a mean temperature summer insolation induces even in high latitudes.

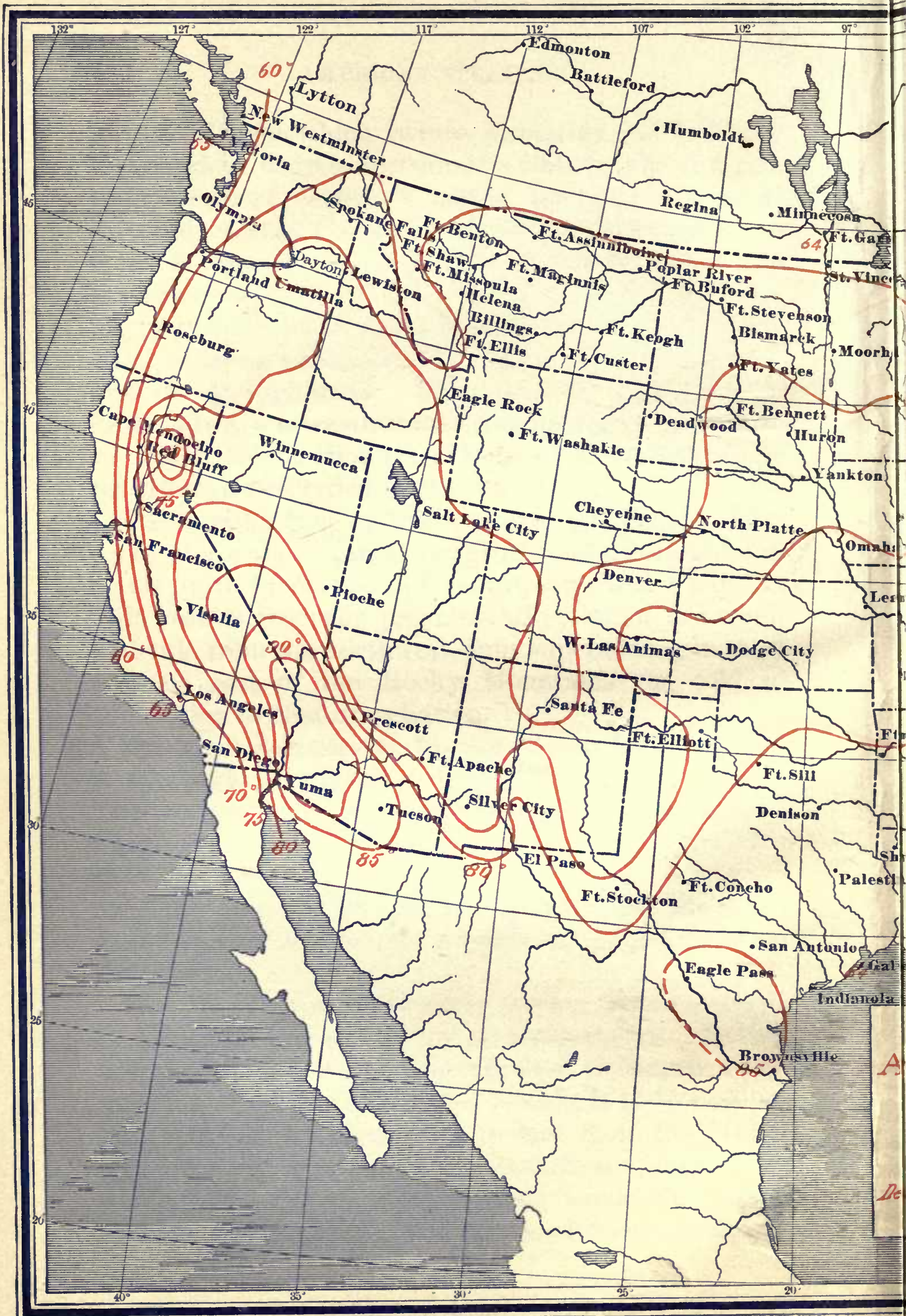
St. Louis, Mo., and Yuma, Ariz., are inland stations, while New York City, Jacksonville, Fla., San Diego, Cal., and Vizagapatam, India, are littoral stations, to which may be added Massowah, Red Sea, as it is so near to the mainland as to feel its climatic influence. The annual curve of Singapore, nearly under the equator, illustrates by its flatness the slight variability of temperature at insular stations in low latitudes.

On Charts V. and VI. the temperature conditions of the United States are shown by the isotherms for January, the coldest, and for July, the warmest months of the year. It is to be noted that the coldest locality is in the Red River Valley and the adjacent parts of Manitoba, the temperature decreasing regularly toward that region from the Gulf of Mexico, the Atlantic and Pacific oceans. The small angle at which the rays of the winter sun reach that section, the length of the night and the almost total absence of aqueous vapor, form conditions which reduce insolation and facilitate to a marked degree nocturnal radiation. In addition the movement eastward, across the great lakes, of cylconic storms, results in drawing southward enormous masses of cold air from Saskatchewan. This movement of cold air is facilitated by the peculiar physical features of the country, a broad valley with gently sloping sides, devoid of heavy timber and unbroken by highlands. This cold of translation is nearly always intensified by rapid nocturnal radiation, so that in this section occur some of the lowest single temperatures recorded in the world.

The modification of temperatures by oceanic influences along the Atlantic and Gulf coasts during January is quite inconsiderable, as appears from Chart V. This results from the prevalent direction of the wind, which is from the northwest, thus superadding in most sections east of the Rocky Mountains the cold of translation to that of radiation.

The most remarkable feature of the January chart is the high temperature of the Pacific coast region. The decrease in the temperature of January from Charleston, on the Atlantic coast, to Eastport is 30°; from San Diego, Cal., to Tatoosh Island, the decrease is only 12°, which is but slightly greater than the range in the temperature of the surface of the sea between these points.

The distribution of pressure during January tends to facilitate this equability of temperature. During this month the actual pressure over California is increasing, while in Oregon and Nevada it is decreasing, the result of the air flowing inward from the higher area over the Pacific. The circulation of prevailing winds thus induced brings westerly winds with much aqueous vapor, almost constant cloudiness, and nearly



132°
127°
122°
117°
112°
107°
102°
97°
Edmonton
Battleford
Lytton
New Westminster
Victoria
Humboldt
Olympia
Spokane Falls
Regina
Minnecosa
Ft. Benton
Ft. Assinniboine
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Dayton
Lewiston
Helena
Poplar River
Ft. Buford
Portland
Umatilla
Ft. Stevenson
Bismarck
Roseburg
Billings
Ft. Keogh
Ft. Ellis
Ft. Custer
Ft. Yates
Eagle Rock
Ft. Bennett
Deadwood
Huron
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Yankton
Sacramento
Salt Lake City
Cheyenne
North Platte
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Santa Fe
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Tucson
Silver City
Denison
El Paso
Ft. Concho
Ft. Stockton
San Antonio
Eagle Pass
Indianola
Brownsville
60°
65
64
75
80
85
70°

erage Temperature
for July.
ced from 18 years observations.
Anticosti
Father Pt.
Chatham
Sidney
Quebec
Prince Arthur's Landing
Duluth
Marquette
Rockliffe
Montreal
Halifax
Eastport
Yarmouth
Burlington
Mt. Washington
Portland
Mackinaw City
Parry Sound
Escanaba
Alpena
St. Paul
Sangeen
Toronto
Kingston
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
Milwaukee
Detroit
Erie
Williamsport
New Haven
New Shoreham
Dubuque
Chicago
Toledo
New York
Sandy Hook
Des Moines
Davenport
Sandusky
Cleveland
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Norfolk
Cape Henry
Springfield
Lynchburg
Kittyhawk
Cairo
Hatteras
Nashville
Knoxville
Charlotte
Chattanooga
Ft. Macon
Memphis
Wilmington
Smithville
Little Rock
Augusta
Starkville
Atlanta
Charleston
Vicksburg
Savannah
Montgomery
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
57°
64°
65°
70°
75°
80°
82°
81°

continuous rain to the regions north of California. The prevailing winds in Northern California are, however, northerly, and in Southern California northeasterly. However, the enclosed valleys of the Sacramento and San Joaquin, the Mohave Desert, and the various mountain ranges are not favorable to steady winds, so that fortunately many interruptions occur in the circulation, and westerly winds along the coast are not infrequent in Southern California, and quite frequent on the central coast, thus bringing large quantities of aqueous vapor which is locally deposited, with an ameliorating effect on the temperature.

Dr. Haughton * has calculated that on the west coast of Ireland the heat from rainfall is equivalent to half that from the sun.

It seems to the author that the rainfall in the Pacific coast region very largely affects the mean temperature. It is significant that San Diego, with its 7 inches of winter rain, has a normal seasonal temperature for its latitude, but to the northward the precipitation for the winter increases to 14 inches at San Francisco and 31 at Tatoosh Island, with a similar increase in abnormally high temperature for the latitude, the excess at Tatoosh Island being nearly 10°.

It is in summer, however, that the effects of the sea winds are most evident along the Pacific coast, as will be seen by reference to the July chart, No. VI., of mean temperatures. Without exception the coast winds prevail very largely from the west, the ocean air being drawn inward owing to the high temperature and consequently reduced pressure of the inland valleys. The gradient is so gentle, however, that the aqueous vapor

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* Haughton also says : " One gallon of rainfall gives out latent heat sufficient to melt 75 lbs. of ice, or to melt 45 lbs. of cast iron."

drawn in from the sea is taken up quickly by the dry inland air, very rarely causing condensation.

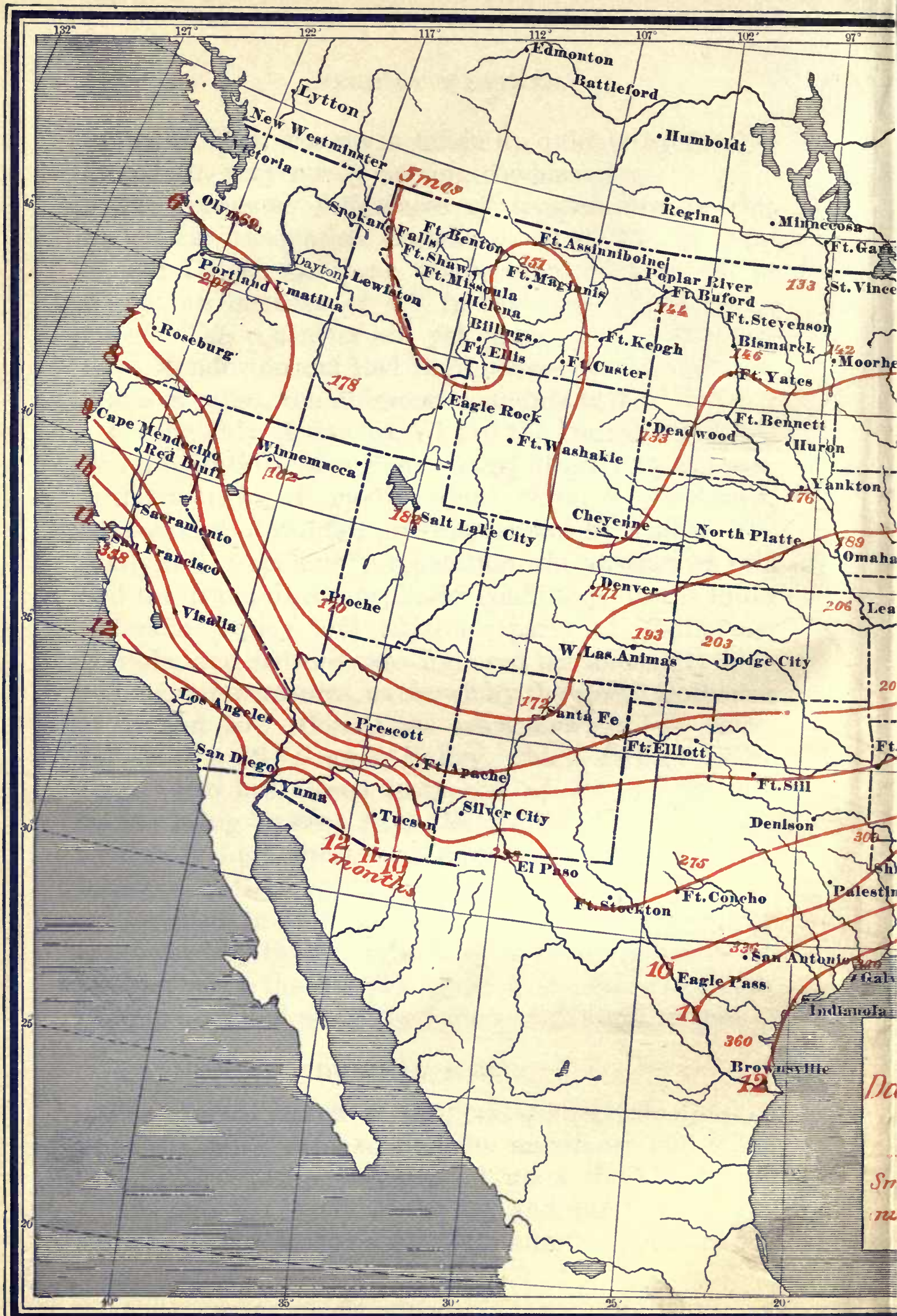
The enormous differences of temperature in this region are unequalled elsewhere. From 67° in July at San Diego, the mean temperature rises to 92° at Yuma, an increase of 25° in less than two hundred miles. The contrasts are yet more striking between Cape Mendocino and Red Bluff, where, in less than one hundred miles, the difference amounts to 28°.

On the July chart (No. VI.) of the United States are two illustrations of regions heated directly by the sun, without material modifications through cloudiness, evaporation of rainfall, or transference by winds. The sandy soil, with scanty vegetation, the absence of rain and the tranquil atmospheric conditions in the lower Colorado Valley and adjacent parts of California, Nevada, and Arizona, are followed by unusually high summer temperatures, as shown by the closed isotherms of 85° and 90°. Conditions are somewhat less favorable in the Rio Grande Valley, which, farther to the south, also has closed isotherms of 85° and 90°, the former being present from the middle of May. These unusually high mean temperatures continue in both locations until about the autumnal equinox.

Elsewhere in July the isotherms are bent materially southward by the cooling effects of the great lakes, by sea breezes on the Atlantic coast from Maine to North Carolina, as well as by the various mountain ranges.

DIURNAL MARCH.

The diurnal march of temperature depends directly upon the sun's rays, so that the maximum and minimum phases principally depend upon the absence of clouds and the length of the day and duration of sunshine. As a rule, the daily maximum temperature oc-



Edmonton
Battleford
Lytton
New Westminster
Humboldt
Victoria
Regina
Minnecosa
5 mos
Ft. Benton
Ft. Assinniboine
Spokane Falls
Ft. Shaw
Ft. Maginnis
Poplar River
Ft. Buford
Ft. Missoula
Helena
Olympia
Portland
Dayton
Umatilla
Lewiston
Billings
Ft. Stevenson
Bismarck
Ft. Keogh
Ft. Ellis
Ft. Custer
Ft. Yates
Roseburg
Eagle Rock
Ft. Bennett
Deadwood
Huron
Ft. Washakie
Cape Mendocino
Red Bluff
Winnemucca
Yankton
Cheyenne
North Platte
Omaha
Sacramento
Salt Lake City
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Santa Fe
Los Angeles
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Tucson
Denison
months
El Paso
Ft. Stockton
Ft. Concho
San Antonio
Eagle Pass
Indianola
Brownsville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y Mean Temperature
above 50° Fahr:
ll figures indicate the
ber of days.
Prince Arthur's Landing
Duluth
Marquette
Quebec
Rockliffe
Montreal
Parry Sound
Mackinaw City
Escanaba
Alpena
Saugeen
Toronto
Kingston
Oswego
Burlington
Mt. Washington
Portland
Eastport
Halifax
Yarmouth
Father Pt.
Chatham
Sidney
Anticosti
Boston
Provincetown
New Shoreham
Albany
Buffalo
Port Huron
Grand Haven
Milwaukee
Detroit
Toledo
Erie
Cleveland
Sandusky
Williamsport
New Haven
New York
Sandy Hook
Barnegat
Atlantic City
Pittsburgh
Philadelphia
Baltimore
Washington
Del. Breakwater
Chincoteague
Norfolk
Cape Henry
Kittyhawk
Hatteras
Lynchburg
Charlotte
Knoxville
Chattanooga
Nashville
Memphis
Little Rock
Starkville
Atlanta
Augusta
Wilmington
Smithville
Charleston
Savannah
Jacksonville
Cedar Keys
Montgomery
Vicksburg
Pensacola
New Orleans
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
St. Paul
La Crosse
Dubuque
Des Moines
Davenport
Keokuk
Champaign
Indianapolis
Columbus
Cincinnati
Springfield
St. Louis
Louisville
Cairo
6 mos
7 mos
9 mos
10 mos
11 mos
12 mos
124
135
142
158
172
174
216
250
292
310

curs from 2 to 4 P.M., although in regions where the air is very dry, or the effect of the sun's rays very small, it may occur before 2 P.M. The daily minimum occurs generally about dawn, at that hour when the effect of the terrestrial radiation is counteracted by reflected heat from the upper strata of the atmosphere from the morning sun. In winter the minimum has a tendency

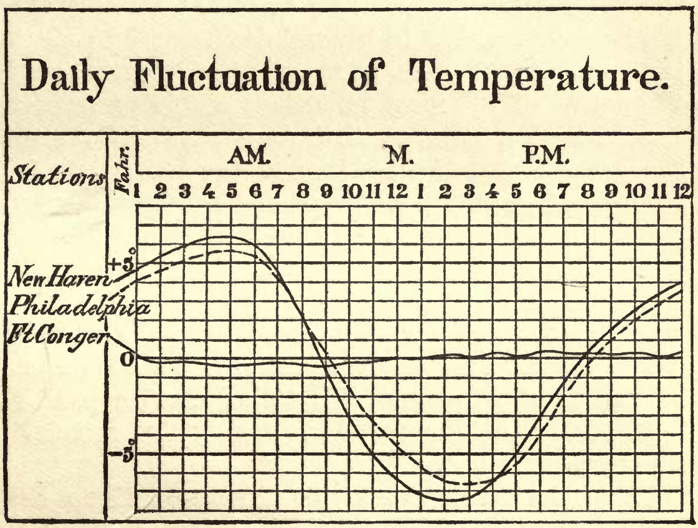


Fig. 20.

to occur slightly before dawn, while in summer it is somewhat delayed.

Purely local causes, such as the influence of sea breezes or the recurrence of rain, tend to change the hour of the maximum, especially in low latitudes.

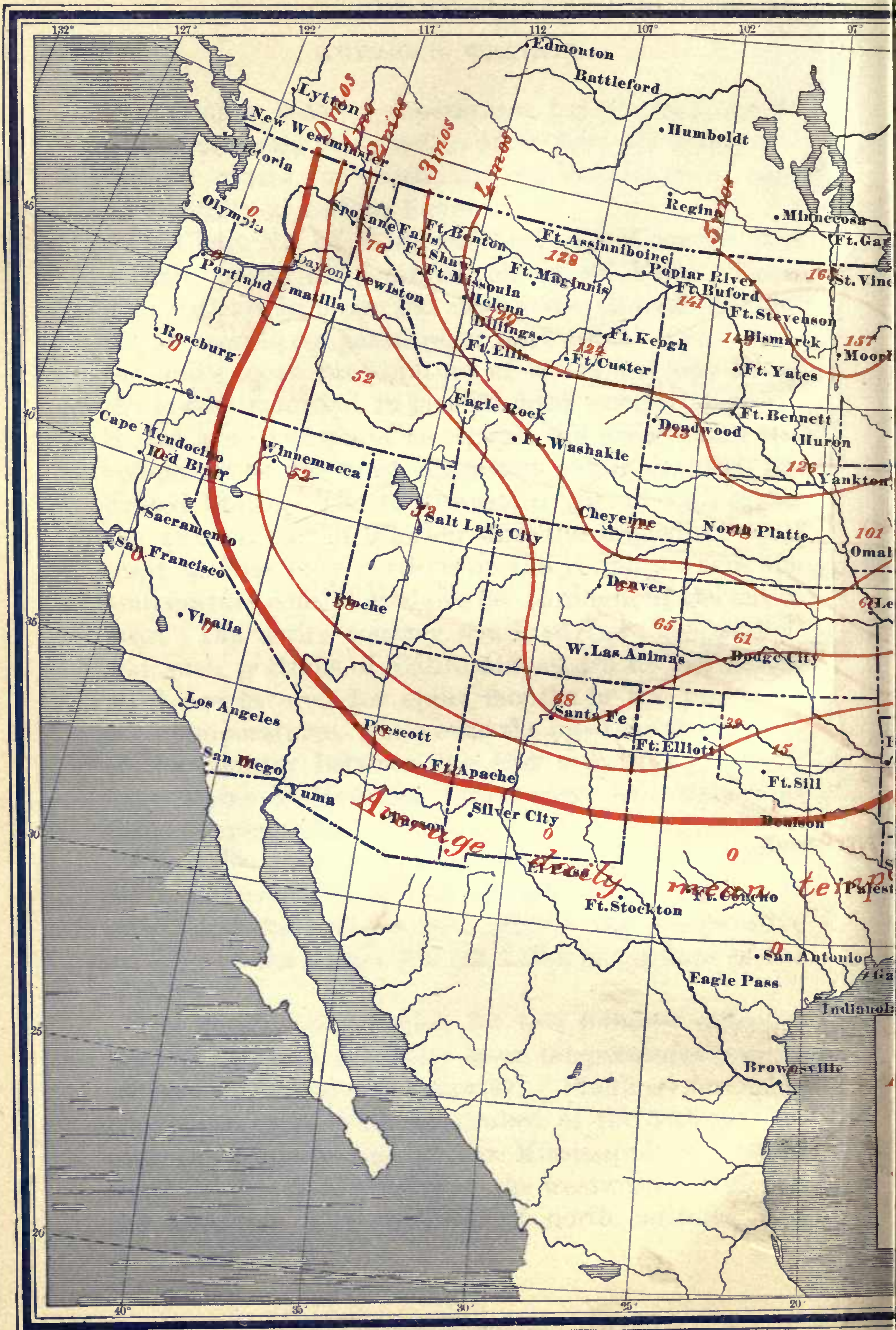
The diurnal march of temperature is illustrated by Fig. 20, which shows the diurnal changes at various stations. The data is for the entire year, except at

Fort Conger, where temperatures for the long Arctic winter are used in order to show that the absence of the sun causes the maximum and minimum to occur accidentally at various hours.

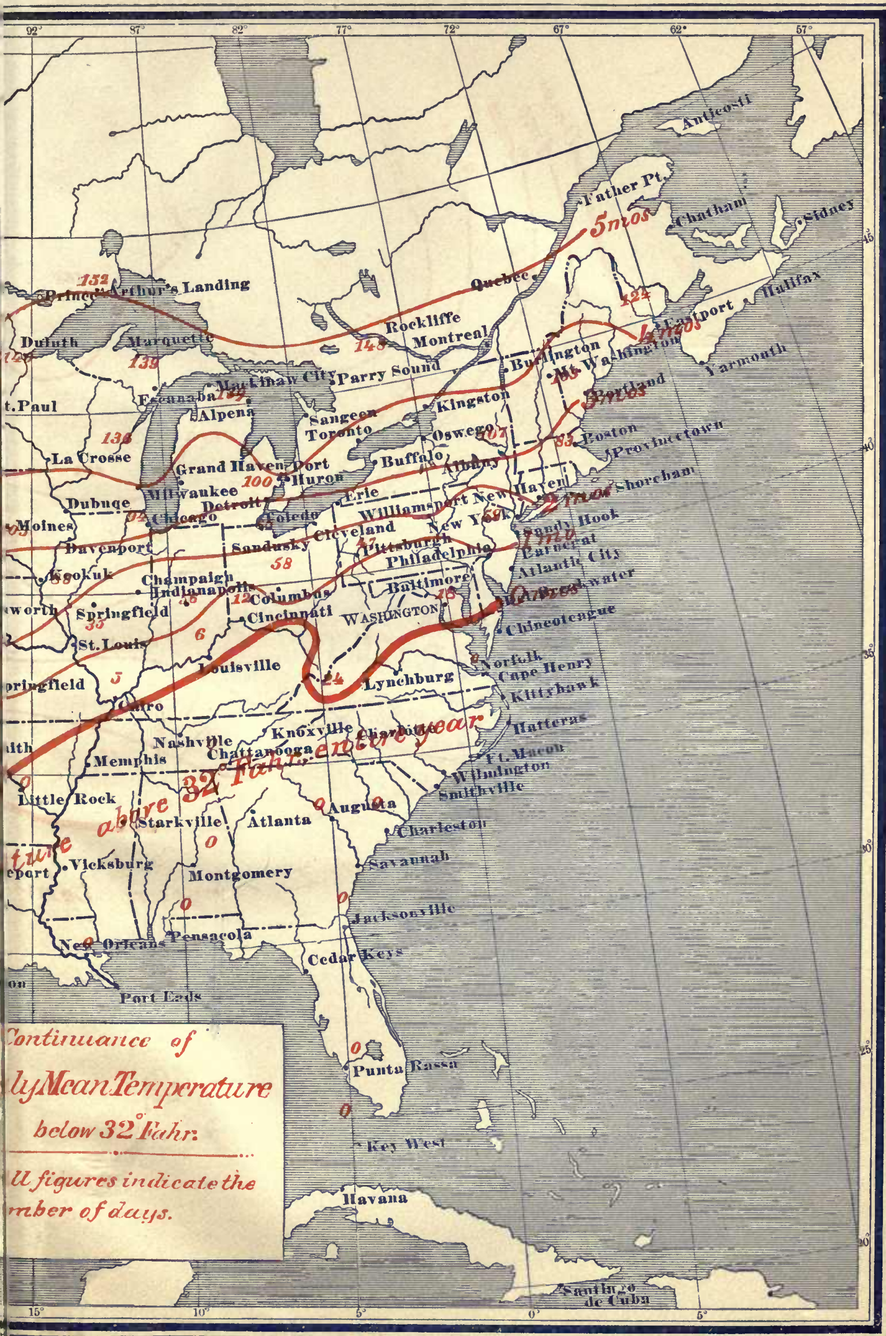
On Chart No. IX. is shown the length of continuance of daily mean temperatures above 50° Fahr. These data indicate in a marked degree the climatic character, as regards temperature, of the United States ; since the daily mean temperature of 50° is not only about the lowest mankind in general deem comfortable, but is also a critical point as regards the growth and development of the most important staple crops of the United States. The southwestern part of California, the greater part of Florida, and the immediate Gulf coast are the only portions of the country where the temperature continues above 50° throughout the entire year. The entire country south of the 35th parallel, and such portions of California as are to the northward, are favored for eight months in the year with such temperatures, while even the most northern parts of the country between the 45th and 49th parallels, from Maine to Montana, have nearly five months of these temperatures.

Chart No. X. shows the continuance of the daily mean temperatures of the United States below 32° Fahr., and thus shows at a glance the comparative severity of the winter for the different portions of the country.

The Pacific coast region for two hundred miles inland is free from any daily mean temperatures (except on very rare occasions) below 32°. Similarly favorable conditions exist to the southward of the 38th parallel over the country east of the Mississippi River and south of the 35th parallel to the westward. Between the 45th and 49th parallels of north latitude, and



132°
127°
122°
117°
112°
107°
102°
97°
Edmonton
Battleford
Lytton
New Westminster
Victoria
Humboldt
Regina
Minnecosa
Olympia
Spokane Falls
Ft. Benton
Ft. Assinniboine
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Poplar River
Ft. Buford
Dayton
Portland
Umatilla
Lewiston
Helena
Ft. Stevenson
Billings
Ft. Keogh
Bismarck
Roseburg
Ft. Ellis
Ft. Custer
Ft. Yates
Eagle Rock
Ft. Bennett
Deadwood
Huron
Ft. Washakie
Yankton
Cape Mendocino
Red Bluff
Winnemucca
Cheyenne
North Platte
Sacramento
Salt Lake City
San Francisco
Denver
Pioche
Visalla
W. Las Animas
Dodge City
Los Angeles
Santa Fe
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Tucson
Denison
El Paso
Ft. Concho
Ft. Stockton
San Antonio
Eagle Pass
Indianola
Brownsville
0 mos
1 mo
2 mos
3 mos
4 mos
5 mos
Average daily mean temp
40°
35°
30°
25°
20°


92°
87°
82°
77°
72°
67°
62°
57°
Anticosti
Father Pt.
Chatham
Sidney
5 mos
Quebec
Prince Arthur's Landing
152
124
Halifax
Eastport
4 mos
Rockliffe
Montreal
148
Duluth
Marquette
139
Parry Sound
Burlington
Mt. Washington
Yarmouth
Mackinaw City
Escanaba
Alpena
St. Paul
Kingston
Portland
3 mos
Sangeen
Toronto
Oswego
107
Boston
Provincetown
138
La Crosse
Buffalo
Albany
Grand Haven
Port Huron
100
Milwaukee
Detroit
Erie
New Haven
2 mos
Shoreham
Dubuque
Chicago
Toledo
Williamsport
New York
Sandy Hook
Moines
Davenport
Sandusky
Cleveland
1 mo
Pittsburgh
Barnegat
58
Philadelphia
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Springfield
Cincinnati
WASHINGTON
Chincoteague
35
6
St. Louis
Louisville
Norfolk
Cape Henry
Springfield
5
Lynchburg
24
Kittyhawk
Cairo
Hatteras
Nashville
Knoxville
Charlotte
Chattanooga
Memphis
entire year
Ft. Macon
Wilmington
Smithville
32° Fahr.
above
Little Rock
Augusta
Starkville
Atlanta
Charleston
Vicksburg
Montgomery
Savannah
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
15°
10°
5°
0°
5°
45°
40°
35°
30°
25°
20°
Continuance of
Mean Temperature
below 32° Fahr.
figures indicate the
number of days.

from Montana eastward to Northern Maine, the severity of the weather in winter is shown by the fact that the average daily temperature is below 32° for periods averaging from four to five and a half months, the longest continuance of such temperature being in the valley of the Red River of the North, the station at St. Vincent, Minn., having on an average five and a half months' daily temperatures below the melting point of ice. The same station also has the least number of days of mean temperature above 50°, —133 days annually.

The months of January and July have been selected as representative months, since they are, as a rule, for the Northern Hemisphere the coldest and warmest months, respectively, of the year.

In the United States the greatest mean obtains in July as a whole. As a marked exception the month of August is warmer along the immediate Pacific coast, from San Diego, Cal., to Sitka, Alaska. From local causes San Francisco does not attain its maximum monthly heat until September. The lowest monthly temperature in the United States falls in January, except in Alaska and the Aleutian Islands, where it obtains in February.

In some portions of the globe, generally between the equator and thirty degrees north latitude, the month of June is slightly warmer than that of July; this is especially true of India, owing to the rainy season setting in. The highest monthly mean temperatures of the Northern Hemisphere occur, nevertheless, in May and in India, as is indicated by the following data:

Mooltan, Indus Valley, 30.2° N., 71.5° E., 420 feet elevation (15 years), 93.9°; Agra, inland, 27.2° N., 78° E., 555 feet elevation (22 years), 94.5°; Bickaneer, 28° N., 73° E., 744 feet elevation (8 years), 95.0°;

Jacobabad, Indus Valley, 28.4° N., 68° E., 185 feet elevation (8 years), 95.9°, the extreme of high monthly temperatures.

At Vizagapatam, on Bay of Bengal, 17.7° N., 83.4° E., 31 feet elevation (16 years), the annual temperature is 82.8°. This is only exceeded by the records of Massowah, an island in the Red Sea, where the annual temperature, dependent on a record of a few years, however, is the highest, perhaps, in the world. The highest annual and monthly temperatures in the United States are those of Yuma, Ariz., 32.8° N., 114.5° W. (12 years), annual, 72.1°, July, 92.0°; Fort Mojave, Ariz. (8 years), annual, 72.7°, July, 94.9°; Rio Grande City, Tex. (7 years), annual, 73.1°, June, 93.9°.

The absolute maximum for a single month in the United States is that for July, 1882, 97.3°, at Rio Grande City, Tex. The lowest mean temperatures in the United States are at St. Vincent, Minn. (10 years), annual, 34°; January, 4.8°. The absolute lowest mean monthly temperature (13.4°) occurred at this station, January, 1883.

INTERRUPTIONS OF TEMPERATURE.

The increase of temperature from January to July and the decrease during the rest of the year do not occur with absolute and unbroken regularity. Every storm which passes across the United States affects for the time being the normal march of temperature, and replaces the gradual and almost imperceptible seasonal changes by the more sudden and violent accidental fluctuations. As will be seen later, in treating of storms and cold waves, these accidental variations of temperature last about three days only. The recurrences of the most marked of these accidental changes, year after year, are so marked that they have impressed themselves on the public mind. The warm days of the early year known in New England as the

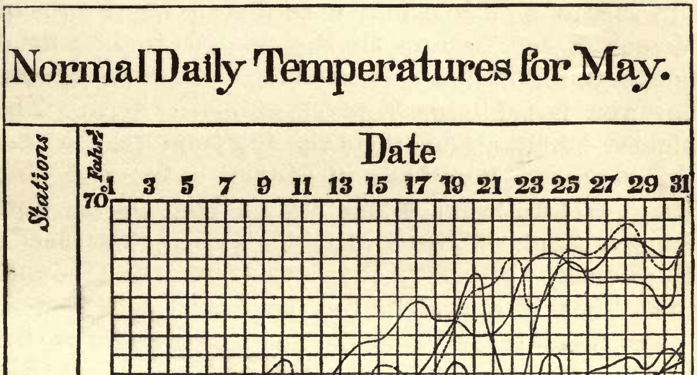


Fig. 21.

"January thaw," the cold days of April, called by the Scotch "Borrowing Days," and the "cold days of May" are the best and most widely known of these interruptions.

The cold days of May, being common to both Europe and America, thus merit examination. Their appearance in Scotland is placed by Buchan from May 9th to 14th, while in America they are supposed to occur from May 10th to 15th.

In Fig. 21 are charted the normal mean temperatures for each day of May for Omaha, Neb. ; Chicago, Ill. ; Toledo, O. ; Buffalo and Oswego, N. Y. ; Philadelphia, Pa., and Lynchburg, Va. These means have been calculated from observations varying from fourteen to sixteen years. It will be noticed that the interruptions of temperature between May 5th and 25th are marked and persistent. Two peculiarities appear, however—viz. :

1st. That if a straight line be drawn cutting the mean temperature of both the first and last day of the month at each station, the greatest departures from the line are the high temperatures from May 17th to 22d, so that the marked feature in the United States is rather the warm than the cold days of May.

2d. That the phases of heat and cold, more especially the latter, apparently pass from northwest to southeast, as they occur first at the more westerly or northerly stations.

It further appears that these marked departures do not obtain in the St. Lawrence Valley, in New England, to the south of the 35th parallel, nor to the westward of the Missouri Valley.

A detailed examination proves conclusively that these interruptions of temperature arise from the passage of low area storms from west to east, which induce abnormally high temperatures, to be followed later by high areas in the rear. These high areas, drawing southeastward the dry cold air from British America, produce the sudden and abnormal falls of temperature known popularly as "cold waves." As Buchan said, twenty years since, interruptions of temperature depend on differences of atmospheric pressure, which induce either equatorial or polar currents, according to the relative position of the storm centre.

It is evident from an examination of weather conditions attendant on warm days in the northern parts of the United States during January, that they result from the movement of low-area storms eastward, in paths of unusually high latitudes, thus inducing southerly winds for a few days over the regions favored by abnormally high temperatures.

As will appear later in this work, there is no sufficient reason to support a belief in recurring cycles, for any locality, of excessive or deficient phases of rainfall, or indeed of temperature, although one may admit that the amount of solar heat for the whole world may be greater in the year of minima sun spots than in the maxima.

CHAPTER X.

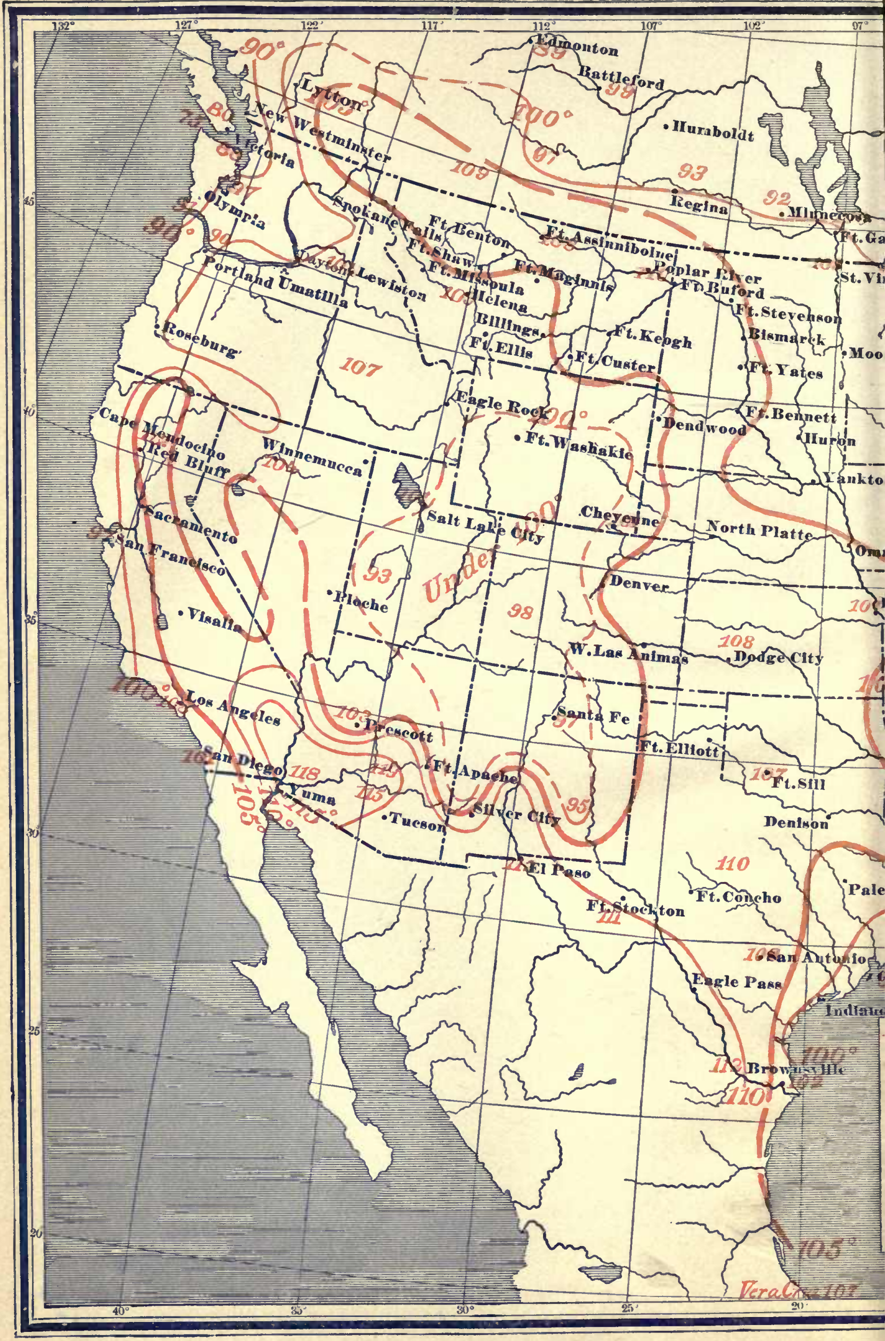
RANGES, VARIABILITY, AND EXTREMES OF TEMPERATURE.

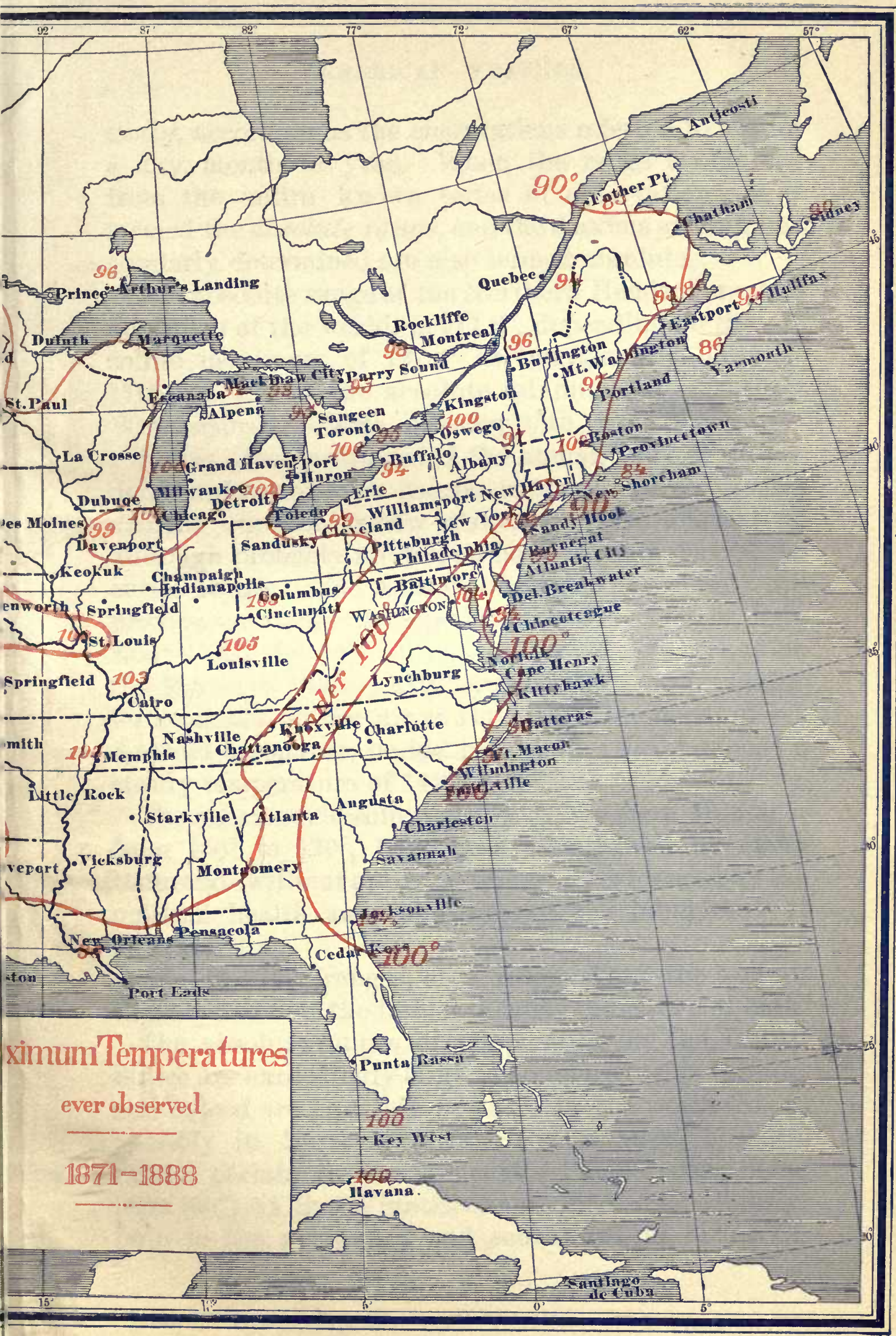
One of the most important elements of any climate is its range of temperature, which marks it as continental or marine.

The marked feature of continental climate is the great difference between its extreme temperatures, whether of day, month, or year. The greatest differences occur in the interior of continents, where the small amount of aqueous vapor in the air permits rapid radiation in winter and a high degree of insolation in summer. These differences may be called extreme in North America, where they almost equal the excessive ranges of Central Asia.

On the contrary, a marine climate is characterized by small ranges and a general freedom from violent changes. The annual fluctuation in the monthly mean at Singapore, a tropical marine station (Fig. 19), is only 3.7°. In the United States may be instanced Tatoosh Island, San Francisco, and San Diego, characteristic marine stations of the Pacific coast, with differences between the hottest and coldest months of 8°, 9°, and 15° respectively. The continental stations of Werchojansk, Siberia, and Saint Vincent, Minn., have differences between similar months of 120.4° and 70.7° respectively.

The difference between extreme temperatures at a station is called the *range*, and is *annual*, *monthly*, or


Edmonton
Battleford
Humboldt
Lytton
New Westminster
Victoria
Olympia
Spokane Falls
Ft. Benton
Ft. Assiniboine
Regina
Minnecosa
Ft. Shaw
Ft. Missoula
Helena
Ft. Maginnis
Poplar River
Ft. Buford
Ft. Stevenson
Bismarck
Ft. Yates
Dayton
Lewiston
Portland
Umatilla
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Roseburg
Eagle Rock
Ft. Washakie
Deadwood
Ft. Bennett
Huron
Yankton
Cape Mendocino
Red Bluff
Winnemucca
Sacramento
San Francisco
Salt Lake City
Cheyenne
North Platte
Under 100°
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Santa Fe
Prescott
Ft. Elliott
San Diego
Yuma
Ft. Apache
Ft. Sill
Tucson
Silver City
Denison
El Paso
Ft. Concho
Ft. Stockton
San Antonio
Eagle Pass
Brownsville
Vera Cruz
90°
100°
105°
110°
115°


ximum Temperatures
ever observed
1871–1888
Antícosti
Father Pt.
Chatham
Sidney
Quebec
Halifax
Eastport
Yarmouth
Rockliffe
Montreal
Burlington
Mt. Washington
Portland
Prince Arthur's Landing
Duluth
Marquette
St. Paul
Escanaba
Mackinaw City
Parry Sound
Alpena
Sangeen
Toronto
Kingston
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
New Shoreham
Milwaukee
Detroit
Erie
Williamsport
New Haven
Dubuque
Chicago
Toledo
Cleveland
New York
Sandy Hook
Des Moines
Davenport
Sandusky
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Norfolk
Cape Henry
Springfield
Cairo
Lynchburg
Kittyhawk
Hatteras
Nashville
Knoxville
Charlotte
Chattanooga
Memphis
Wilmington
Little Rock
Augusta
Starkville
Atlanta
Charleston
Vicksburg
Savannah
Montgomery
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
92°
87°
82°
77°
72°
67°
62°
57°
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°
5°
90°
100°
100°
100°
105
103
106
96
98
99
86
97

daily, according as the observations referred to are for a day, month, or year. When the range is obtained from the entire known series of observations, it is termed the *absolute range*, and the maxima and minima similarly determined are also termed absolute.

The absolute range of the Northern Hemisphere, and doubtless of the world, is 217.8°, depending on the absolute maximum of 127.4° at Ouargla, Algeria, July 17th, 1879, and the absolute minimum of —90.4° at Werchojansk, Siberia, January 15th, 1885.

It was once questioned if the human body could undergo unharmed such enormous temperature changes, and the question is now answered in the affirmative, although probably no person has ever experienced the entire range. The author, however, has closely approximated it, having experienced at Fort Conger, February, 1882, the very low temperature of —66.2°, and on the Maricopa Desert, Ariz., August 28th, 1877, saw the temperature of the air at 114°, while the metal of his Aneroid barometer, beside him as he rode, assumed a steady temperature of 144°.

The enormous absolute ranges of Northern Montana, from 150° to 170°, have been experienced by many thousands without apparent injury, as evidenced by the unusual health and robustness of the inhabitants of that Territory.

The *absolute* ranges, as a rule, exceed the *annual* slightly ; so that the former is fairly indicative of both.

The absolute ranges of temperature in the United States are exceedingly large as compared with Europe, and indeed are equalled nowhere in the world except possibly in Northern Asia. The smallest absolute ranges pertain to the immediate Pacific coast, being least (60°) at San Francisco, and increasing slightly, both to the northward and southward, to 61° at Tatoosh Island and 69° at San Diego. Except a narrow fringe of land along the Pacific Ocean and a similar narrow fringe along the South Atlantic and Gulf coasts, the absolute range of temperature everywhere exceeds 100°; the range increasing rapidly as one goes inland, and, as a rule, decidedly so with elevation and latitude —*i.e.*, with the lessening thickness of the superincumbent strata of the atmosphere, and the increasing dryness of the air. Ranges exceeding 120° have occurred over a great part of the Ohio Valley, the whole Upper Mississippi and Missouri valleys, and the northern half of the Rocky Mountain and plateau regions. The ranges exceed 140° for all Dakota and Montana; and in the latter Territory the maximum absolute ranges of the United States have been experienced—namely, 169.8° at Fort Benton and 172.7° at Poplar River.

The absolute ranges for any place in the United States may be approximately determined from Charts VII. and VIII., which show the absolute maximum and minimum temperatures for the whole country.

The greatest absolute ranges of the globe are those recorded in the interior of Siberia, where the variations in temperature somewhat exceed those of Montana. The extreme ranges are Yeniseisk, 169°; Banschikowo (62° N., 132° E.), 175°; Werchojansk (67.5° N., 134° E.), 178°; and Yakutsk, 181.4°; the last doubtless the greatest in the world.

In India absolute ranges of temperature rarely equal 100°; the greatest in the Punjab. The absolute range at Galle, on the coast of Ceylon, is but 24.4° from 92.0° to 68.6°; for the year 1875 it was 16.2°. At Nancowry, Bay Islands, the annual range in 1879 was 17.8°. In no year does it exceed 19°. In Algeria absolute ranges exceeding 100° are not usual, except along the edge of Sahara. At Bon Saada, 35° N., however, an annual range of 128.8° has been observed.

The absolute range of *annual temperature* is to a considerable extent dependent on locality, appearing to increase with latitude and with distance from the sea. It rarely exceeds 8° in the United States, and according to Loomis, amounted to only 6.3° in eighty-six years at New Haven, Conn., a sea-coast station. At Bismarck, Dak., however, it amounted to 9.3° in nine years.

Extreme *monthly* ranges of or exceeding 100° are occasionally observed in Montana, Dakota, and Nebraska, while along the Atlantic seaboard ranges exceeding 70° are unknown, and on the Pacific coast barely equal 55°. Fort Benton, Mon., has reported the greatest monthly range in the United States, 117°, from 58° on December 12th, 1880, to —59° on the 29th. The greatest range at Tatoosh Island, Wash. Ter., in any month is but 41.4°, while Key West has had a range of 46°. At San Francisco, Cal., the range for January, 1884, was 16°. Galle, Ceylon, in July, 1877, had a range of 7.1°, and at Paramaribo, South America, the range in October, 1878, was only 7.0°, perhaps the smallest ever recorded at any place.

Of more vital importance than *absolute* or *monthly* range is the *daily* range, since violent or extreme changes of temperature within a few hours are harmful to vegetable and animal life and growth.

Over the United States, from the Mississippi Valley eastward, the *mean daily range* varies throughout the different months of the year from 12° to 20°. The daily range from the Missouri Valley and Texas westward, except along the Pacific coast line, varies from 20° to 35°. The only portion of the country favored by very small daily ranges is that portion of the Pacific coast situated on or within a hundred miles of the Pacific

Ocean. The highest daily ranges occur, as a rule, in the summer months, from May to July, inclusive, except along the South Atlantic and Gulf coasts, where the greatest daily ranges occur in the winter months—December or January. The mean daily ranges are least in December and January, except in Texas, along the Gulf and South Atlantic coasts, where they generally attain the minimum in September. There are local departures from these general rules, usually caused by the prevailing wind shifting to or from the sea, or by the intervention of cloud and rain. In these cases the aqueous vapor plays a very important part in modifying the ranges, which otherwise would often be extreme.

Fig. 22 contains typical curves showing the annual fluctuation of the mean daily ranges at selected stations in the United States.

The daily ranges over the Rocky Mountain and plateau regions are extraordinary, and it is evident that Buchan, when writing of the great range of 41.3° at Pachbudra, India, during a single month—March, 1880—was unaware of the extraordinary daily fluctuations of the temperature in Arizona and Southern California. At Fort Apache, Ariz. (elevation, 5050 feet), the mean daily range for June is no less than 42.6°. These figures are not greatly in excess of the ranges at Prescott (elevation, 5340 feet) and Fort Grant, Ariz. (elevation, 4860 feet), at which places the average daily range for the same months is 36°. Even as remarkable as are these ranges they are exceeded at Campo, Cal. (elevation, 2710 feet), where the mean range for September is 45.4°, and from June to October, inclusive, averages 44.8°. *Average daily ranges* during single months have somewhat exceeded these amounts. At Fort Apache, in June, 1888, the daily range averaged 45.7° ; Phœnix,

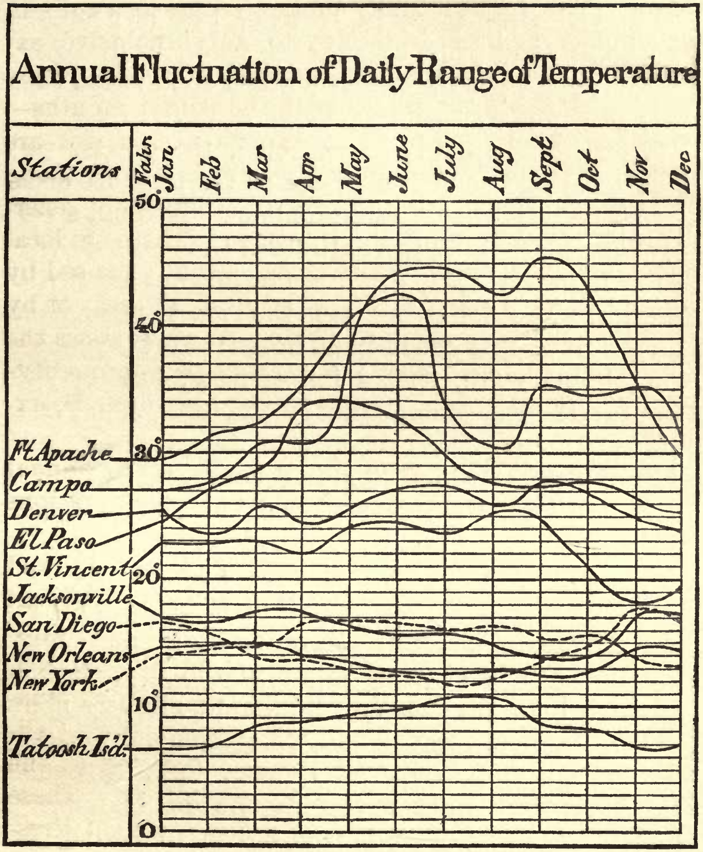


FIG. 22.

Ariz., June, 1879, 48.4° ; Campo, Cal., September, 1880, 48.8°, June, 1881, 49.0°, and in June, 1880, the mean daily range was 50.6°.

Among stations having small daily ranges for a single month may be selected Key West, Fla., December, 1877, 6.6° ; San Francisco, Cal., December, 1881, 6.5°, and Fort Canby, Wash. Terr., December, 1885, 6.1°.

The stories are many in Texas of 100° at noon and ice at night, and while all such tales may be dismissed as apocryphal, yet they rest on better foundation than many others less startling.

As might reasonably be expected, the greater part of extreme and sudden changes of temperature occur in Dakota, Minnesota, and Montana. It is not a cold of radiation, but is almost entirely of translation, owing to the intensely cold, dry air flowing out of British America. The following are the most remarkable changes from this cause in 24 hours: Fort Maginnis, Mon., January 6th, 1886, a fall of 56.4°, 49.7° of it in 8 hours; Helena, Mon., January 6th, 1886, 55.0°, 50.6° of it in 16 hours; Deadwood, Dak., January 21st, 1886, a fall of 55.3°, of which 46.2° in 8 hours and 54.2° in 16 hours; Denver, Col., December 27th, 1886, a fall of 60.4°, 34.3° of it in 8 hours; Lamar, Mo., February 11th, 1887, a fall of 60.3°, 58.5° of it in 9 hours; Abilene, Tex., December 27th, 1886, a fall of 63.3° in 16 hours.

In Arizona, California, Nevada, Utah, and Texas very remarkable changes occur in the dry, elevated regions, where the morning minimum, slightly above the freezing-point, occasionally rises from 40° to 60° by noon or shortly after. At Denver, Col., November 27th, 1886, the temperature rose 47.3° in 8 hours, and on January 19th, 1886, it rose 53° in 16 hours; Las Animas, Cal., February 5th, 1887, there was a rise of 58°, and February 27th, 1887, a rise of 55°, 52° of it in 8 hours; Fort Apache, Ariz., six rises took place in June, 1886, of 50°, of which four cases occurred in 8 hours, the greatest, 55.9°, in 24 hours, and 50.6° in 8 hours; Campo, Cal., June 23d, 1882, 59° rise, 55.1° in 8 hours, and Florence, Ariz., June 22d, 1881, 65° rise, 50° in 8 hours. This last instance is the greatest daily variation as far as known. Its accuracy is confirmed by other extreme ranges in Arizona on that day, notably by a rise at Tucson of 54°, 44° of it in 8 hours.

In Thibet it is said the temperature has been known to fall 90° from (20° C., 68° F., to —30° C., —22° F.) in about 15 hours, from the mid-day maximum to morning minimum. This statement may reasonably be questioned in view of the ranges given above, and also since at Leh, Ladak, a dry elevated station west of Thibet, the range of any month does not exceed 60°, and of the year is but 91.4°.

MAXIMUM AND MINIMUM TEMPERATURES.

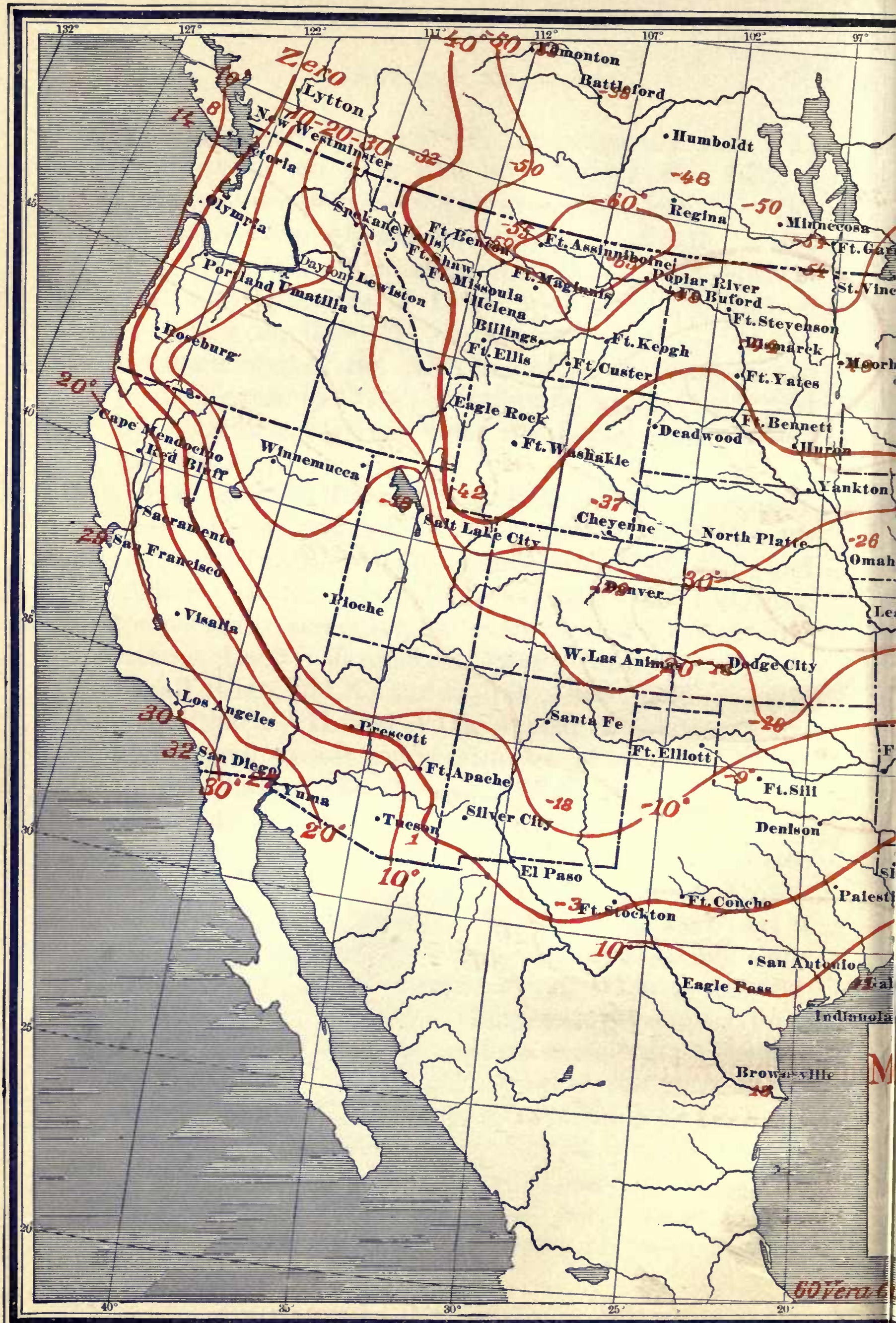
According to Mr. S. A. Hill, Meteorological Reporter for Central India, amateur observers in Australia occasionally are in rivalry as to who can obtain the highest readings. All meteorologists who have discussed miscellaneous data have had occasion to question the accuracy of extreme thermometer readings.

Statements regarding extreme temperatures must always be received with more or less caution, owing not only to the imperfection and incorrectness of thermometers, but also on account of unsuitable exposure. Within the past eighteen years much attention has been given to these points, and consequently readings from the different weather services may be received with a greater degree of credibility than previously obtained. The highest temperatures of the world occur over the desert of Sahara, the plains of India, in the interior of Australia, and in the valleys of the Gila and Southern Colorado in America.

With regard to maximum temperatures from the Sahara there is no definite information, but we have the most carefully made and reliable readings from the Algerian system, at the stations of which the simoom blows from the Sahara. It appears, however, that temperatures exceeding 120° F. are unusually rare. At Orleansville, on July 21st and August 21st, 1881, a temperature of 120.6° was observed, and in July, 1880, at Tizi Ouzon, Algeria, a temperature of 121.1°. On July 17th, 1879, at Aumale, Algeria, the very extraordinary temperature of 125.6° was registered, and on August 27th, 1884, at Ouargla, 32° N., 5° E., on the northern edge of the African desert, the temperature of the air rose to 127.4°, probably the highest registered by a trained observer from a reliable, well-exposed thermometer.

It would seem that very high temperatures are equally rare in India, which country has constantly been credited with extraordinary temperatures of 130° and higher. In ten years (1875–84) only the following temperatures exceeding 120° were registered: Agra and Lahore, 120.3°; Jacobabad, 120.9°, Sialkot, and Dera Ismail Khan, 32° N., 71° E., 125°, June, 1875.

On Charts VII. and VIII. appear isotherms of the highest and lowest temperatures ever recorded in the United States. The charts are based primarily on observations of the United States Signal Service, owing to the uniformity of exposure and the fact that corrections have been made for the very common errors, especially in low readings. It will be noticed that a considerable uniformity, without regard to latitude, appears in the highest temperatures, which practically range from 100° to 110°. Temperatures higher than 100° have occurred in all sections except along the immediate Pacific coast, in the region of the great lakes, over the Blue Ridge, Allegheny, and the high portions of the Rocky Mountain ranges and at certain stations on the New Jersey and New England coasts. The maximum temperature at Tatoosh Island is the lowest in the country (75°), but the series of years is very


Lytton
New Westminster
Victoria
Olympia
Spokane Falls
Ft. Benton
Ft. Shaw
Ft. Missoula
Helena
Ft. Assinniboine
Ft. Maginnis
Dayton
Lewiston
Portland
Umatilla
Roseburg
Battleford
Humboldt
Regina
Minnecosa
Poplar River
Buford
Ft. Stevenson
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Ft. Yates
Eagle Rock
Ft. Washakie
Deadwood
Ft. Bennett
Huron
Yankton
Cape Mendocino
Red Bluff
Winnemucca
Salt Lake City
Cheyenne
North Platte
Sacramento
San Francisco
Visalia
Pioche
Denver
W. Las Animas
Dodge City
Los Angeles
San Diego
Yuma
Prescott
Ft. Apache
Tucson
Silver City
Santa Fe
Ft. Elliott
Ft. Sill
Denison
El Paso
Ft. Stockton
Ft. Concho
San Antonio
Eagle Pass
Indianola
Brownsville
Zero
10-20-30
20°
30°
10°


imum Temperatures
ever observed
1871-1888
Anticosti
Father Pt.
Chatham
Sidney
Halifax
Quebec
Rockliffe
Montreal
Prince Arthur's Landing
Duluth
Marquette
Mackinaw City
Parry Sound
Escanaba
Alpena
Sangeen
Toronto
Kingston
Oswego
Burlington
Mt. Washington
Eastport
Yarmouth
Portland
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Milwaukee
Detroit
Buffalo
Albany
Dubuque
Chicago
Toledo
Erie
Williamsport
New Haven
New Shoreham
Moines
Davenport
Sandusky
Cleveland
New York
Sandy Hook
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Norfolk
Cape Henry
Lynchburg
Kittyhawk
Cairo
Hatteras
Nashville
Knoxville
Charlotte
Chattanooga
Memphis
Ft. Macon
Wilmington
Smithville
Little Rock
Starkville
Atlanta
Augusta
Charleston
Vicksburg
Savannah
Montgomery
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
-40°
-30°
-20°
-10°
Zero
10°
20°
30°
50°

short. The lowest maximum from a series of fifteen years is that of Eastport, Me., 88°. Temperatures exceeding 110° have occurred in the Valley of the Rio Grande, the southern portions of New Mexico, Arizona, and the extreme southeastern part of California.

No temperature observed at any Signal Service station has ever reached 120°. The highest recorded readings have been 119° at Fort McDowell and Phœnix, Ariz., June, 1883, and 118° at Yuma, Ariz., July, 1878. From other observations are quoted temperatures of 128° at Mammoth Tank, Cal., July, 1887; 122° at Humboldt, Cal., July, 1887; 121° at Fort Miller, Cal., June, 1853; Fort Boise, Ida., August, 1871; 120° at Fort McRae, N. M., June, 1873; 119° at Fort Mojave, Ariz., August, 1875, June, 1876, and July, 1877; Fort Yuma, Cal., July, 1877; Fort Miller, Cal., July, 1853. The highest temperatures ever recorded in the various States and Territories are to be found in table No. 7.

The lines of lowest temperatures are much more regular. The only portions of the country where the temperature does not sink below zero, Fahrenheit, are California, Arizona, the immediate coasts of Oregon, Washington Territory, and Delaware, and about 200 miles inland along the South Atlantic and Gulf coasts. The considerable elevation, high latitude, and great dryness of the air in Northern Montana favor nocturnal radiation into space, and thus cause some of the lowest temperatures known on the face of the globe.

The temperature of space, or, as it is known, the absolute zero, is placed at —493° F., so that there is an enormous margin between the temperature of interplanetary space and the lowest recorded temperature of the world, —90° at Werchojansk.

The impression is general that temperatures of forty degrees below zero are not uncommon in the United

States. Such is not the fact, as, except on the summit of Mount Washington, this degree of cold has been reported only from the following Signal Service stations in Dakota, Northern Minnesota, and Northern Montana. *Montana:* Poplar River, —63.1° (January 1st, 1885); Fort Benton, —59° (December); Fort Assiniboine, —55.4° (February); Fort Custer, —47.5° (December); Fort Shaw, —44.5° (December); Fort Maginnis, —42.0° (February); Helena, —40.5°; *Dakota:* Fort Buford, —48.2°; Bismarck, —43.6°; Fort Totten, —43°; Huron, —42.8°; Fort Yates, —41.0°; *Minnesota:* Moorhead, —47.5°; St. Vincent, —51° (December, 1873). Unless otherwise noted, the readings occurred in January.

On the summit of Mount Washington the temperature of —50° has been observed on Pike's Peak, —39.1.

Other instances of temperatures forty degrees below zero have been recorded, many being most doubtful readings, while others are probably a few degrees in error, owing to the fact that the instruments have not been tested for low temperatures.

The following are the most reliable:

Colorado: Fort Garland, —40° (1873); *Dakota:* Webster, —44° (1887); Fort Randall, —44° (1875); *Iowa:* Vail, —40° (1881); Humboldt, —42° (1885); *Michigan:* Fort Brady, —47° (1873); *Minnesota:* Fort Ripley, —44° (1860); Fort Ripley —43° (1863); Northfield, —41° (1885); *Montana:* Fort Ellis, —53 (1872); *Vermont:* Port Mills, —42° (1887); Lunenburg, —45° (1872); Randolph, —40° (1872); *Wisconsin:* Embarras, —40° (1875); Neillsville, —42° (1885); Fond du Lac, —42° (1887); *Wyoming:* Fort Laramie, —40° (1864).

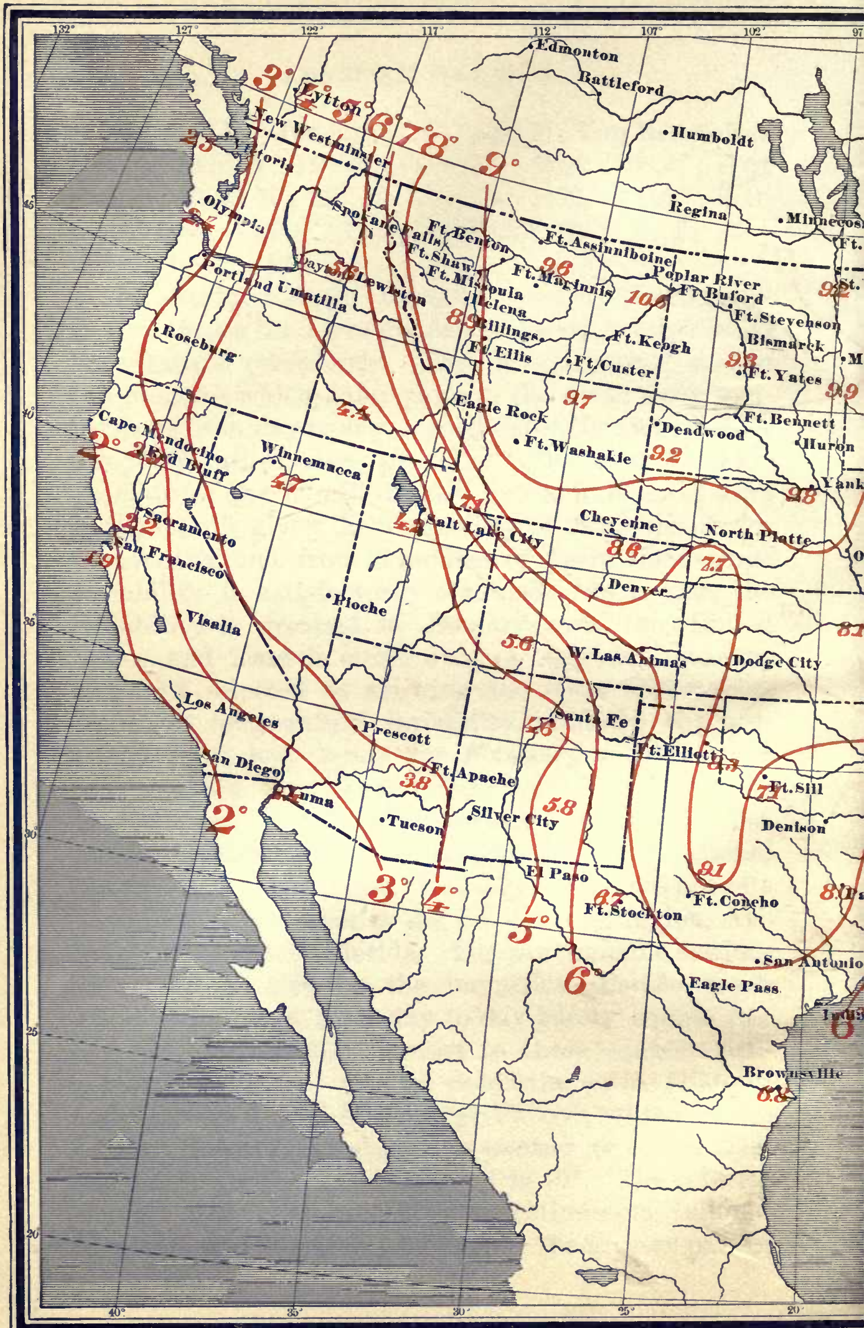
Central Siberia presents most favorable conditions for very low temperatures, elsewhere unequalled.

The lowest monthly mean temperatures, as well as the lowest single temperatures in the world, have been noted at Werchojansk, Siberia, 67.5° N., 134° E., at which place, on January 15th, 1885, the remarkably low temperature of —90.4° was observed, and the average temperature for the month was —63.9°, while the average temperatures for February and December were but slightly less. In the same year and place other minimum temperatures occurred as follows: February, —84.3°; March, —77.4°; December, —78.2°; in the latter month the highest temperature recorded was —33°. This station is situated in the valley of the Iana, at an elevation of about 330 feet above the sea. From the latitude of the station the sun is absent during December, while its elevation above the horizon for the rest of the winter is so slight that the effect of the direct rays of the sun are unable to counteract the intense cold caused by radiation. As might be expected, the percentage of cloudiness is small during the winter months, averaging about 38 per centum, and being least in January, the month of greatest cold. Usually the weather is perfectly calm. In January, 1886, 87 calms were reported in 91 observations, and in December 63 calms out of 85 observations.

During January, 1886, which was an unusually cold month for Siberia, very low temperatures were observed elsewhere, as follows: Banscht Schikowo, 58° N., 109° E., —80.5°; Marchinskoe, 62° N., 130° E., —78.7°; Olekminsk, 60° 22′ N., 59° E., —69°.

It is a common belief that the cold of the Arctic archipelago, in the neighborhood of the North Pole, is more intense during the winter than in the interior of great continents, but such an opinion is not substantiated by the records of lowest temperatures observed by various polar expeditions, which are as follows: Mercy Bay, 74° N., 118° W., January, 1853, —64.9°; Van Rensselaer Harbor, 78.5° N., 71° W., February, 1854, —66.4°; Fort Conger, 81.7° N., 65° W., March, 1876, —70.8°, February, 1882, —62.1°; Floeberg Beach, 83.5° N., 61° W., March, 1876, —73.8°.

The character of any climate is perhaps characteristically shown in no more forcible manner than by its temperature *variability*. This is obtained by noting the changes which take place in the mean daily temperature from day to day, regardless of the fact whether the temperature rises or falls. The sum of these changes for any month divided by the number of days in the month gives the variability of temperature for that month, and from a number of years the average variability is satisfactorily obtained. As a rule, the variability is greatest in January over the United States, and least in either July or August. January has been selected as showing the most unfavorable phases of temperature variability, although the variability is slightly larger for February in the greater part of Michigan, Western New York, Pennsylvania, New Jersey, Maryland, Delaware, and Eastern Virginia. It is evident that the only portions of the United States where the changes from day to day are not of a very decided character is the Pacific coast region, Arizona, and Southern Florida. The most equable stations are those situated on the immediate Pacific coast, where the change from day to day barely equals two degrees. In striking contrast to these equable temperature conditions may be noted the entire Missouri and extreme Upper Mississippi Valleys, where during January the average change to warmer or colder from one day to another ranges from 8° to 10°. The severest changes are experienced in Western Minnesota, Dakota, Montana, and Western Idaho, over the greater part of



132°
127°
122°
117°
112°
107°
102°
Edmonton
Battleford
Humboldt
Regina
Minnecosi
Lytton
New Westminster
Victoria
Olympia
Spokane Falls
Ft. Benton
Ft. Assinniboine
Poplar River
Ft. Buford
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Helena
Ft. Stevenson
Bismarck
Portland
Umatilla
Dayton
Lewiston
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Ft. Yates
Roseburg
Eagle Rock
Deadwood
Ft. Bennett
Huron
Ft. Washakie
Cape Mendocino
Red Bluff
Winnemucca
Salt Lake City
Cheyenne
North Platte
Sacramento
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Santa Fe
Ft. Elliott
Los Angeles
Prescott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Denison
Tucson
El Paso
Ft. Concho
Ft. Stockton
San Antonio
Eagle Pass
Brownsville
3°
4°
5°
6°
7°
8°
9°
2°
40°
35°
30°
25°
20°

Variability of Temperature for January

which the differences from day to day nearly amount to ten degrees. The largest winter difference in the entire country occurs at Eastport, a station noted for its equable temperature conditions during August and September, but which averages nearly 12° for January and 10° for February.

During July and August the variability is small throughout the entire United States, and along the Pacific, Gulf, and South Atlantic coasts amounts on the average to only a degree and a half; the smallest being 1.0° at San Diego, and the largest 2.0° at Jacksonville. The largest summer ranges are found in Lake Superior region, Dakota, and Montana, generally varying between four and six degrees.

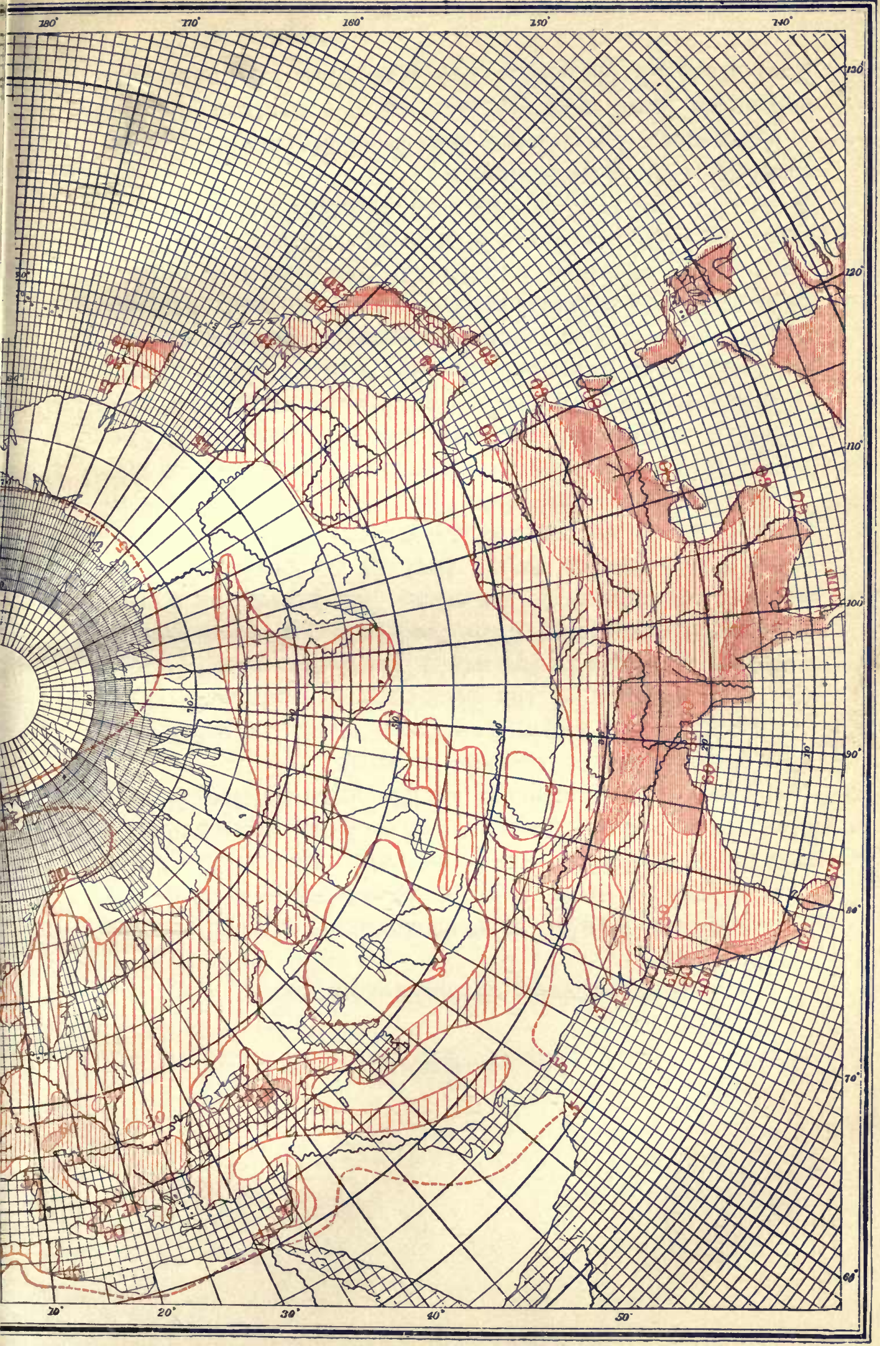
CHAPTER XI.

DISTRIBUTION OF RAIN AND SNOW.

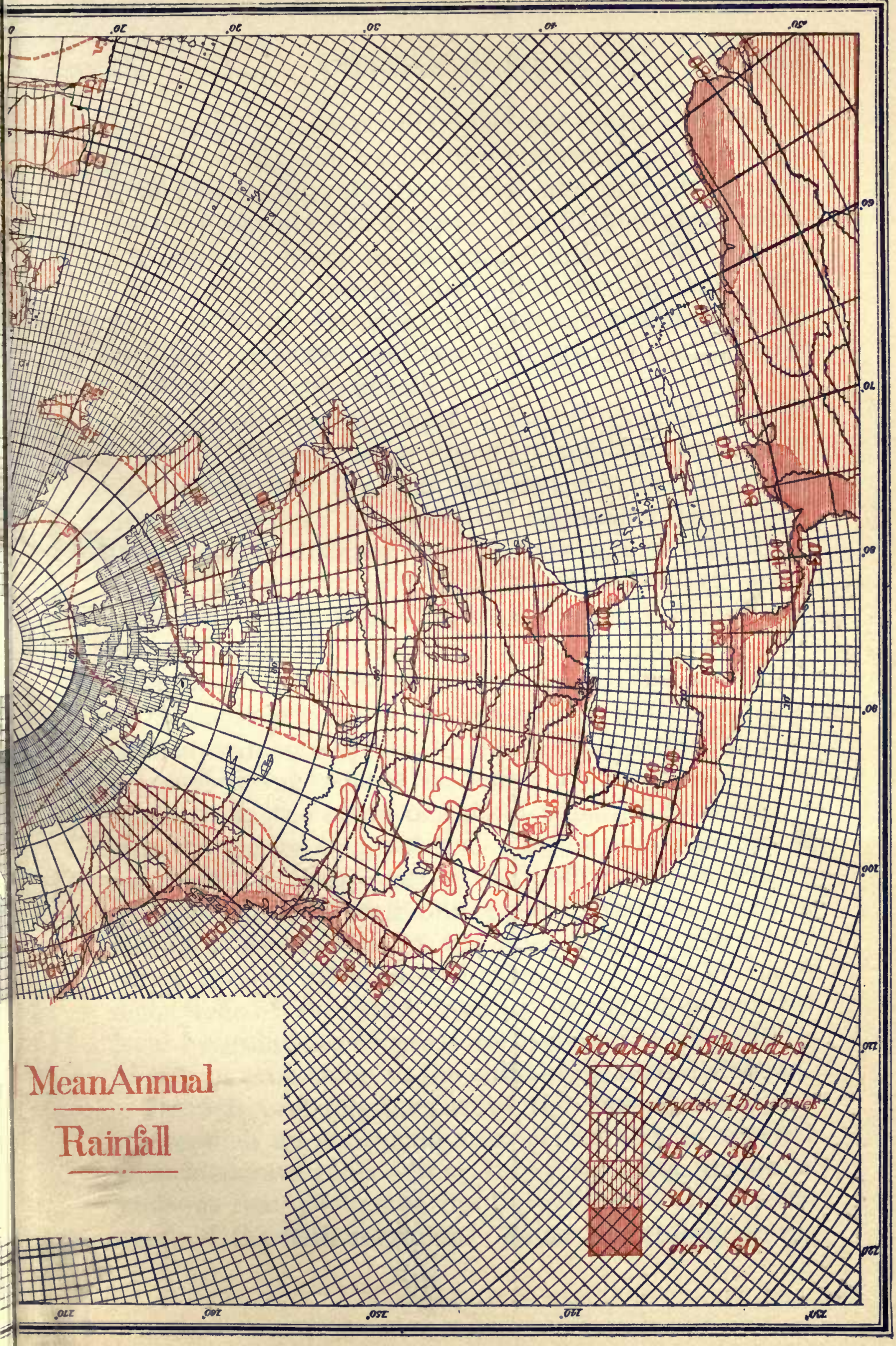
ALTHOUGH rainfall is comparatively a local phenomenon, yet in order to give an adequate idea of its general distribution, it is necessary to assume that from observations made at scattered stations we can obtain fairly accurate opinions as to the precipitation occurring over extensive intervening areas.

Chart No. XI. shows the mean annual rainfall for the land surface of the Northern Hemisphere. The heaviest rainfalls in the world are found on the western or southern coasts of the Eastern and Western Hemispheres contiguous to the seas. The prevailing winds bring the aqueous vapor that is so copiously deposited along the immediate coasts of these regions. In low latitudes the prevailing northeast trades also bring heavy rainfalls, as appears along the northern coast of South America and Central America. The least rainfall (five inches or less) occurs, where it might be reasonably expected, in the North Polar regions, where the very low mean temperature permits the air to contain but a comparatively small amount of aqueous vapor. Detached localities to the leeward of mountain ranges in the interior of great continents, such as Asia and America, are also as scantily favored with rainfall as the Arctic regions.

From carefully collated data John Murray, Esq., has estimated that over twenty-two per centum of the land areas of the earth has less than ten inches of



180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°
60°
10°
20°
30°
40°
50°


Mean Annual
Rainfall
Scale of Shades
under 15 inches
15 to 30
30 .. 60
over 60

rain annually; over thirty-one per centum has from ten to twenty-five inches fall; sixteen per centum, from fifty to seventy-five inches, and six per centum has over seventy-five inches. The highest mean rainfall occurs in Sumatra, about 130 inches; the least in Greenland, 15.5 inches, closely followed by Australia, 15.7. In North America only sixteen per centum of the area has under ten, and less than two per centum over seventy-five inches of rain.

The annual average rainfall, including melted snow, over the United States varies in different sections of the country from less than four inches to more than one hundred inches; the quantity depending largely on the elevation, distance from the ocean, and the direction either of the prevailing wind of the locality, or on accidental winds caused by the passage of storm centres across the country.

In the United States the last-mentioned condition is the most conducive to rainfall, for while precipitation is occasionally fed by local evaporation, yet its preponderating source is found in the vapor-laden winds from the ocean or inland seas. It thus results that the centre of aspiration induces winds favorable for rainfall in some quarters and unfavorable in others. Blanford has pointed out that Kurrachee, with a steady monsoon wind of 400 miles daily, is not necessarily favored with precipitation; but that in India deflections of the wind from its normal direction by local irregularities of pressure increase the probability of rain in proportion to the amount of such deflection.

There is probably no part of the face of the globe where such an enormous area of country is favored with moderate rains—from thirty to sixty inches a year—as that portion of the United States to the eastward of the 97th meridian. From Minnesota, Iowa, and Missouri, eastward to the Atlantic coast, the annual rainfall varies from thirty to forty-five inches. Southward of the 37th parallel the quantity of rain yearly is somewhat greater, ranging generally between forty-five and sixty inches.

It is a general and tolerably accurate rule that the rainfall in the United States decreases with increasing distance from the ocean, and so incidentally with the elevation ; but the variations are markedly different on the Pacific coast from those to the eastward of the Rocky Mountains. Along the Pacific coast the rainfall is greatest at the extreme northwestern point, and decreases quite regularly with the latitude, being least at the extreme southwestern part. Contrary to this rule, the rainfall of the Atlantic coast, with local exceptions, decreases from south to north.

An annual rainfall exceeding forty-four inches occurs along the Atlantic coast and Gulf coast, in the valleys of the Lower Mississippi, Lower Ohio, Cumberland, Tennessee, and Lower Arkansas rivers, and along the Pacific coast to the northward of the 40th parallel. Except in a few favored spots, such as the Yellowstone Park, the rainfall is less than twenty inches over the country situated between the 100th and the 121st meridians. In Southern Nevada, Southeastern California, Western Arizona, and Southwestern Utah, to the leeward of the mountain ranges, less than eight inches fall annually, and in certain localities even less than three inches.

The astonishing increase of rainfall along the Pacific coast—from twelve inches at San Diego to twenty-four at San Francisco, eighty-three at the mouth of the Columbia River, and one hundred and five inches at Neah Bay, Wash. Terr.—is a striking climatic characteristic of that region. Indeed, Cape Flattery, the northwestern point of the United States, may be called a maximum rain centre, since from it the rainfall diminishes in all directions to the eastward and southward.

The heaviest rainfall in that section occurs on the immediate coast during the winter, when monthly rainfalls exceeding twenty inches are not very unusual at exposed points. Yearly falls of 100 inches or more are of record at several points, and the annual rainfall at Neah Bay is 105.2 inches. The following are the falls exceeding 100 inches for single years: *Washington Territory:* Neah Bay, 1865–66 (season), 140.9 inches; Tatoosh Island, 1886–87, 112.9. *California:* Nevada City, 1867–68, 115.3; Crescent City, 1881–82, 113.4; Bowman's Dam, 1871–72, 102.2. *Oregon:* Astoria, 1875–76, 112.5. In the United States other heavy rainfalls for a single year are those of Point Pleasant, La., 1880–81 (ten months only), 102.4, and at Baton Rouge, La., 1846, 116.4 inches.

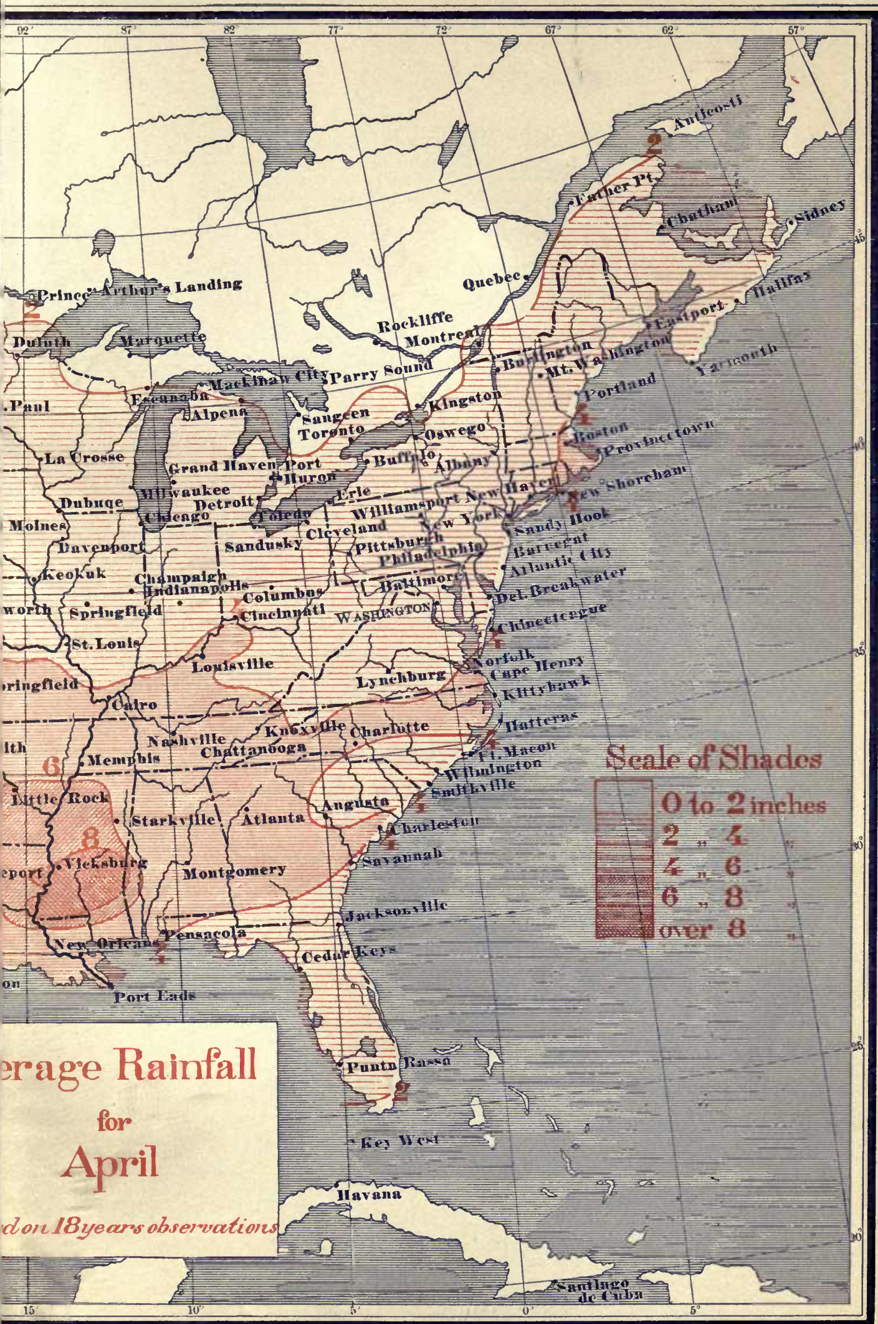
Rainfalls exceeding 100 inches have been recorded in twelve consecutive months at exposed stations in the Atlantic States, among which may be mentioned Mount Washington, 129.23 inches, 1879–80; Cape Lookout, 113.92, 1877–78, and Cape Hatteras, 102.39, 1877–78.

Although the annual rainfall at certain places along the Pacific coast seems very large, yet the average at some points on the west coast of Ireland and Scotland is more excessive. At Seathwaite, Borrowdale, the average annual fall amounts to 154 inches. India, however, far exceeds the rest of the world in the amount of annual precipitation. The immediate southwest coast of India bordering the Arabian Sea, nearly all of British Burmah and Sumatra, have average annual rainfalls exceeding 100 inches.

The rainfall of Cherrapunji, Assam, India, averages 493.2 inches per year, the largest in the world. This enormous rainfall is owing to the station being situated on the side of a mountain, which rises very precipitously 4000 feet, so that the aqueous vapor of the ascending air of the southwest monsoon is condensed by the cold of expansion, and the rain is deposited in torrents. At this station in August, 1841, 264 inches, or twenty-two feet of rain, fell, and in five successive days there was precipitation to the amount of thirty inches in every twenty-four hours. It is stated that in 1860, 699.7 inches, or 58.3 feet, fell at this station, and in 1861 occurred the enormous and almost incredible amount of 905.1 inches, or 75.5 feet. Since 1871 the rainfall has been measured by a government official, and so may be considered fairly trustworthy and accurate, and in this period the annual rainfall at Cherrapunji has varied from 551.9 inches to 283.0 inches, with a maximum monthly rainfall of 184.8 in June, 1876. On June 14th, 1876, 40.6 inches fell in twenty-four hours, an average of 1.7 inches per hour.

Probably the smallest rainfalls in the world occur in Southeastern California and Western Arizona, in and near the valley of the Lower Colorado, and in the section known as the Mohave Desert. The stations which have annually, during the season from July to June, inclusive, falls of rain less than three inches, are: Yuma, Ariz., 2.81 inches; Bishop Creek, Inyo County, Cal., 2.02; Indio, San Diego County, Cal., 1.92; Mammoth Tank (same county), 1.88; Camp Mohave, Ariz., 1.85 inches. These last two stations doubtless have the smallest known rainfall on the face of the globe. Statements have been frequently made that rain never falls in these localities, but there is no year at any station where a measurable rainfall has

132°
127°
122°
117°
112°
107°
102°
97°
Edmonton
Battleford
Humboldt
Lytton
New Westminster
Victoria
Regina
Minnecosa
Olympia
Spokane Falls
Ft. Benton
Ft. Assinniboine
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Poplar River
Ft. Buford
Dayton
Lewiston
Portland
Umatilla
Helena
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Ft. Stevenson
Bismarck
Ft. Yates
Roseburg
Eagle Rock
Deadwood
Ft. Bennett
Huron
Yankton
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Sacramento
San Francisco
Salt Lake City
Cheyenne
North Platte
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Prescott
Santa Fe
Ft. Elliott
San Diego
Ft. Apache
Yuma
Tucson
Silver City
Ft. Sill
Denison
El Paso
Ft. Stockton
Ft. Concho
San Antonio
Eagle Pass
Indianola
Brownsville
0.44
0.81
0.51
0.45
0.44
0.28
0.76
45
40°
35
30°
25
20
40°
35°
30°
25°
20°


erage Rainfall
for
April
d on 18 years observations
Scale of Shades
0 to 2 inches
2 „ 4
4 „ 6
6 „ 8
over 8
Anticosti
Father Pt.
Chatham
Sidney
Halifax
Eastport
Yarmouth
Quebec
Rockliffe
Montreal
Burlington
Mt. Washington
Portland
Boston
Provincetown
New Shoreham
New Haven
New York
Sandy Hook
Barnegat
Atlantic City
Del. Breakwater
Chincoteague
Norfolk
Cape Henry
Kittyhawk
Hatteras
Ft. Macon
Wilmington
Smithville
Charleston
Savannah
Jacksonville
Cedar Keys
Punta Rassa
Key West
Havana
Santiago de Cuba
Prince Arthur's Landing
Duluth
Marquette
Mackinaw City
Parry Sound
Escanaba
Alpena
Saugeen
Toronto
Kingston
Oswego
Buffalo
Albany
St. Paul
La Crosse
Grand Haven
Port Huron
Milwaukee
Detroit
Dubuque
Chicago
Toledo
Erie
Williamsport
Des Moines
Davenport
Sandusky
Cleveland
Pittsburgh
Philadelphia
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Springfield
Cincinnati
WASHINGTON
St. Louis
Louisville
Lynchburg
Springfield
Cairo
Knoxville
Charlotte
Nashville
Chattanooga
Memphis
Little Rock
Starkville
Atlanta
Augusta
Vicksburg
Montgomery
Shreveport
Pensacola
New Orleans
Port Eads
92°
87°
82°
77°
72°
67°
62°
57°
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°
5°

not been recorded, the least observed being that at Indio, 0.10 inch, during the seasonal year 1884–85. Similar stories to the effect that no rain falls for years in parts of Spain, Arabia, Thibet, and Southwestern Siberia may be considered exaggerated and unreliable. The smallest recorded annual rainfall in Spain is six inches. Aden, Arabia, from four years' observations, has a mean rainfall of 2.36 inches; Leh, Ladakh, adjoining Thibet, has a mean of 2.62 inches, from nine years' observations, and Petro Alexandrowsk, N. 41.5°, E. 61°, 2.44 inches. The author knows of no other stations in the Northern Hemisphere where the annual mean rainfall, from recorded observations, is less than three inches.

The United States, in addition to having over the greater part of its surface a moderate rainfall, is also favored in the distribution of rain throughout the year, which generally is as equable in its variation as the annual amounts. In order to better treat, in a general manner, the distribution of rainfall throughout the entire year, the writer has considered a *wet* month as being one in which fifty per centum more rain, and a *dry* month one in which fifty per centum less of the annual rain falls than the average. In like manner, a *very wet* month is one in which double the amount of rain falls, and a *very dry* month one in which less than one quarter of the average rainfall occurs. That is to say, 8.33 per centum of the annual rainfall is the proportional amount for each month, so that a month with 12.5 per centum of the average yearly rain is *wet;* with 16.7 *very wet;* with 4.2 *dry*, and with 2.1 per centum, or less, *very dry*.

So treated, it appears that there is no section of the country from the Atlantic Ocean westward to Michigan, Indiana, Missouri, Arkansas, and Louisiana, which has on an average either a *very dry* or a *very wet* month, and only a few localities even have a *wet* month. February is *wet* in Kentucky and Tennessee; March in Alabama and Georgia, and August along the immediate Atlantic and East Gulf coasts.

There is a well-marked tendency in Illinois, Iowa, the entire Missouri Valley, Nebraska, and Kansas to have a *very wet* May and June, or June and July. Along the valley of the Upper Rio Grande and in Arizona, July and August are, relatively speaking, *very wet* months for these localities, while the Pacific coast region has a *very wet* December and January in the northern part, and January, February, and March in the lower portion. *Very dry* months prevail over the eastern slope of the Rocky Mountains from Dakota southward to Western Texas during December and January. In Arizona June is *very dry*, in Utah, July, and in Oregon, August. In California the months of June, July, August, and September are likewise *very dry*.

In order to illustrate graphically for the year the peculiarly varying distribution of rain in the United States, the monthly mean rainfall for six widely separated stations have been charted in Fig. 23. As far as possible they are representative stations as to locality, and are otherwise typical.

The rainfall curves of the United States, thus charted, represent several characteristic types. The Pacific type, which obtains in the Pacific coast region, has a very marked winter maximum and an equally decided summer minimum; it is here represented by the San Francisco curve.

Along the Pacific coast of the United States the summer is a thoroughly dry season, as rain rarely falls. The frequency of rain and the length of the rainless

FIG. 23.

period become the more pronounced from British Columbia southward to Southern California, and in the southern portions of California the dry season is often unbroken, even by a single passing shower, from May to October.

The trans-Mississippi type, though less decided, as shown by the Omaha curve, is exactly the reverse of the Pacific curve, as it has its maximum in summer and minimum in winter. Arizona, contrary to the generally received opinion, owing to its situation, does not fall under the same rain conditions as the States bordering on the Pacific. Though the winter is marked by occasional rains, yet far the heaviest rainfall occurs in midsummer. It will be found to have a curve with a double inflection, as shown by the diagram for Fort Grant, where the characteristics of both the Pacific and trans-Mississippi types appear combined.

The Atlantic type, while agreeing with the trans-Mississippi as to its summer maximum, is characterized by a spring minimum, and is here represented by New York City.

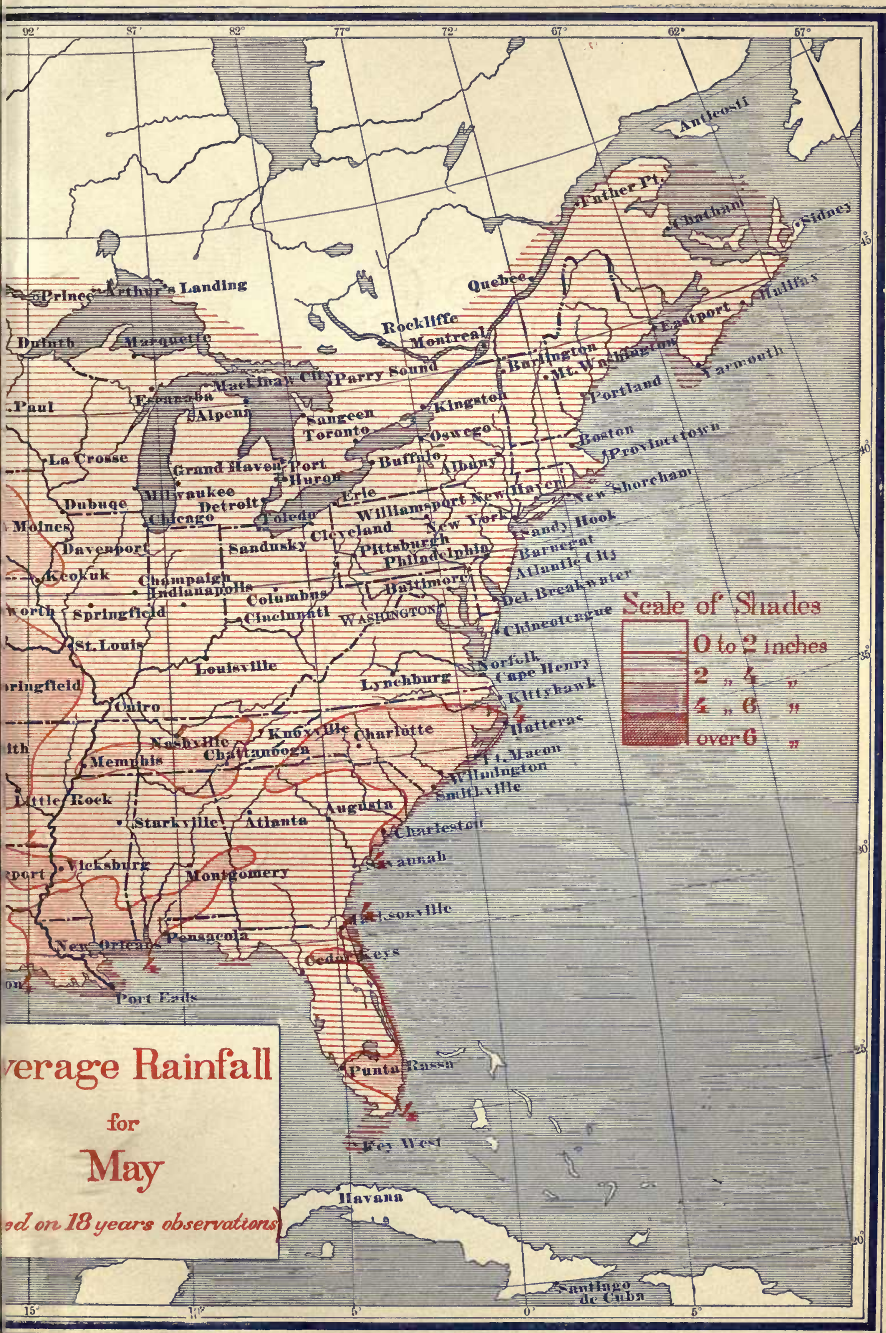
As a somewhat important modification of the prevailing types is to be noted the rainfall of Tennessee and contiguous territory, where, as is shown by the Nashville curve, a very marked winter maximum is followed by a less decided spring minimum.

At Gulf coast stations (see the Galveston curve), the maximum has a tendency to delay until autumn,—the period of cyclones,—while the spring minimum of the Atlantic coast is slightly anticipated.

The variation of rainfall for the same month in different years is extraordinary in some instances, especially along the coasts where the abnormal course of a few low area storms may enormously increase the monthly rainfall, or the absence of the storms leave the region substantially rainless.

The effect of the mean latitude of paths of low areas upon the rainfall of a month is shown by Hellmann,

132°
127°
122°
117°
112°
107°
102°
97°
Edmonton
Battleford
Humboldt
Lytton
New Westminster
Victoria
Olympia
Regina
Minnecosa
Spokane Falls
Ft. Benton
Ft. Assinniboine
Ft. Shaw
Dayton
Lewiston
Ft. Missoula
Ft. Maginnis
Poplar River
Ft. Buford
Portland
Umatilla
Helena
Ft. Stevenson
Billings
Ft. Keogh
Bismarck
Ft. Ellis
Ft. Custer
Ft. Yates
Roseburg
Eagle Rock
Ft. Bennett
Deadwood
Huron
Ft. Washakie
Cape Mendocino
Red Bluff
Winnemucca
Yankton
Cheyenne
Salt Lake City
Sacramento
North Platte
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Santa Fe
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Denison
El Paso
Ft. Stockton
Ft. Concho
San Antonio
Eagle Pass
Indianola
Brownsville
0.84
0.91
0.90
0.15
0.33
0.80
45°
40°
35°
30°
25°
20°



verage Rainfall
for
May
ed on 18 years observations)
Scale of Shades
0 to 2 inches
2 „ 4 „
4 „ 6 „
over 6 „
Anticosti
Father Pt.
Chatham
Sidney
Halifax
Eastport
Yarmouth
Quebec
Prince Arthur's Landing
Duluth
Marquette
Rockliffe
Montreal
Parry Sound
Mackinaw City
Escanaba
Alpena
St. Paul
Burlington
Mt. Washington
Portland
Kingston
Saugeen
Toronto
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
Milwaukee
Detroit
Erie
New Haven
New Shoreham
Dubuque
Chicago
Toledo
Williamsport
New York
Sandy Hook
Des Moines
Davenport
Sandusky
Cleveland
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Norfolk
Cape Henry
Lynchburg
Kittyhawk
Cairo
Hatteras
Knoxville
Charlotte
Nashville
Chattanooga
Memphis
Ft. Macon
Wilmington
Smithville
Little Rock
Starkville
Atlanta
Augusta
Charleston
Savannah
Vicksburg
Montgomery
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
92°
87°
82°
77°
72°
67°
62°
57°
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°
5°

where he points out that through such course the rainfall of the Spanish Peninsula was ten times as great in January, 1881, as during January, 1882.

A similar contrast is offered between September, 1877, with three cyclonic storm centres in the south Atlantic States and an average rainfall of 9.47 inches for the district, as contrasted with September, 1886, when no storm centre passed over the region, and the average rainfall (1.84 inches) was less than one fifth of that in the former year.

Charts XIII., XIV., and XV. show, for the United States, the average rainfall of April, May, and June, as determined from observations of the eighteen years, 1870 to 1887, inclusive.

These months have been selected as covering the period during which vegetables, small fruit, hay, and the cereal crops are practically matured, while by the end of June cotton and large fruits have reached a decisive point in their development. Doubtless the certainty of a crop and the large productivity of the eastern lands depend largely on the extreme regularity, in frequency and abundance, of well-distributed showers in these three months.

The striking feature of these three charts is the wonderful uniformity of rainfall. In April the entire Northern States, from Minnesota, Nebraska, and Kansas, eastward to the Atlantic Ocean, are favored with a generous supply of rain, varying between the narrow limits of two and four inches. To the southward of this locality the average rainfall generally lies between four and six inches, except in Mississippi, where it varies from six to nine inches.

Far the greater portion of the country has a May rainfall between two and four inches. Only over a very small area does the precipitation exceed six inches, while the districts of scanty rainfall are substantially confined to California, Nevada, Arizona, and New Mexico.

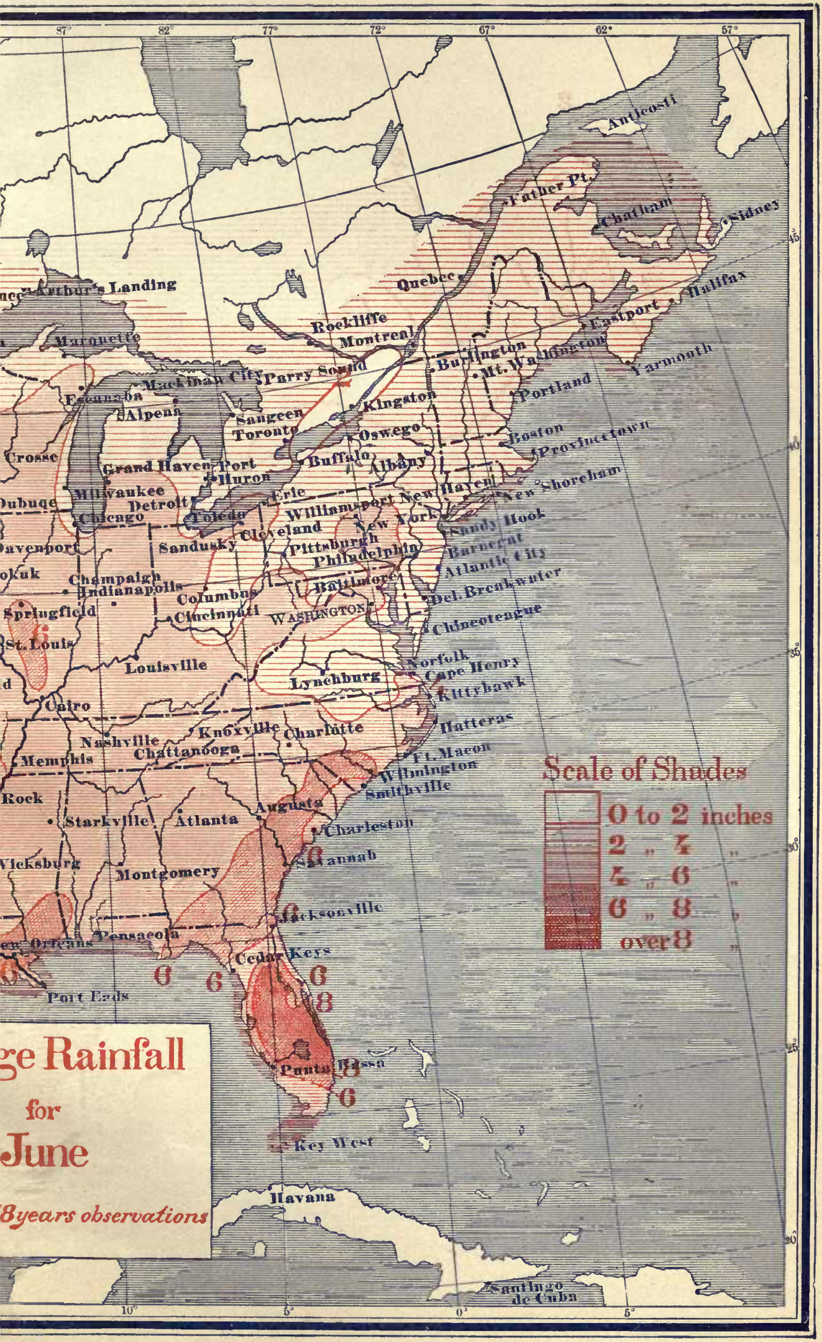
Rainfall during June, a very important growing month, is quite large over the entire country to the eastward of the Missouri Valley, southward to Eastern Texas. In general, the June rainfall is not less than four inches and not over six, the only exceptions being local and of limited extent.

The first rainless month for any part of the United States is April, when no precipitation occurs in the extreme southeastern part of New Mexico and adjacent portions of Arizona. During May no rain falls in the extreme southern portion of Arizona or on the Mohave Desert of California. In June all the southwestern part of Arizona and the southern portion of California are entirely without rain. In July and August no rain falls in California except in the extreme northern portions, but in September the rainless belt is restricted to the southern half of California, and in October to the Mohave Desert and the extreme southern limits of Arizona. In Northwestern Nevada there is a belt of country of above 100 miles wide, immediately eastward of the Sierra Nevada, over which no rain falls from the last of June to the first days of October.

In Table No. 8 is given the greatest monthly rainfall recorded in each State and Territory.

Rainfalls exceeding ten inches in a month, or two and one half inehes in a day, may be called excessive. Such rainfalls are most common in the South Atlantic and Gulf States, from North Carolina to Texas, and in the North Pacific coast region. They occur most frequently from North Carolina to Florida from June to September, inclusive, and from Alabama westward to Southeastern Texas from March to June, inclusive, al-

Edmonton
Battleford
Lytton
New Westminster
Humboldt
Regina
Olympia
Spokane Falls
Ft. Benton
Ft. Assiniboine
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Poplar River
Ft. Buford
Dayton
Portland
Umatilla
Lewiston
Helena
Billings
Ft. Ellis
Ft. Keogh
Ft. Custer
Bismarck
Ft. Yates
Roseburg
Eagle Rock
Deadwood
Ft. Washakie
Cape Mendocino
Red Bluff
Winnemucca
Cheyenne
North Platte
Salt Lake City
Sacramento
San Francisco
Denver
Pioche
Visalia
W. Las Animas
Dodge City
Los Angeles
Santa Fe
No Rainfall
Prescott
San Diego
Ft. Elliott
Ft. Apache
Yuma
Tucson
Silver City
Ft. Sill
Denison
El Paso
Ft. Stockton
Ft. Concho
Eagle Pass
No Rainfall
0.72
0.80
0.34
0.70
0.33
0.11
0.35
0.65
0.46
0.06
0.23
0.75
0.16
0.70
1
2
0



ge Rainfall
for
June
8years observations
Scale of Shades
0 to 2 inches
2 " 4 "
4 " 6 "
6 " 8 "
over 8 "
Anticosti
Father Pt.
Chatham
Sidney
Quebec
Halifax
Eastport
Yarmouth
Arthur's Landing
Marquette
Rockliffe
Montreal
Parry Sound
Burlington
Mt. Washington
Portland
Mackinaw City
Escanaba
Alpena
Kingston
Saugeen
Toronto
Oswego
Boston
Provincetown
Crosse
Grand Haven
Port Huron
Buffalo
Albany
Milwaukee
Detroit
Erie
New Haven
New Shoreham
Dubuque
Chicago
Toledo
Williamsport
New York
Sandy Hook
Davenport
Sandusky
Cleveland
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Norfolk
Cape Henry
Lynchburg
Kittyhawk
Cairo
Hatteras
Nashville
Knoxville
Charlotte
Memphis
Chattanooga
Ft. Macon
Wilmington
Smithville
Rock
Starkville
Atlanta
Augusta
Charleston
Vicksburg
Savannah
Montgomery
Jacksonville
Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba

though in the latter State they sometimes occur in August and September, in connection with the advance of West India cyclones. In Tennessee such rains are not infrequent from January to April, and in the country immediately northward to the Ohio River from May to July, inclusive. In the North Pacific coast region such rainfalls occur as might be expected from January to March. From Virginia northward to Massachusetts these heavy rains are very infrequent, except during the months of August and September. In the States and territories not named, rainfalls exceeding ten inches in a single month, or two and a half inches in twenty-four consecutive hours, are of very rare occurrence, as appears from the records.

The following are among the heaviest and most extraordinary monthly rainfalls which have been recorded in the United States: Upper Mattole, Cal., January, 1888, 41.63 inches, of which 25.0 fell in three consecutive days; Alexandria, La., June, 1886, 36.9 inches; Fort Barrancas, Fla., August, 1878, 30.7; Neah Bay, Wash. Terr., December, 1886, 30.7; Brownsville, Tex., September, 1886, 30.6; Fort Stevens, Ore., January, 1880, 29.8; Fernandina, Fla., June, 1864, 28.9; Newark, N. J., August, 1843, 22.5; Merritt's Island, Fla., September, 1878, 23.8; Wilmington, N. C., July, 1886, 21.1; Jackson, Miss., April, 1874, 23.8; Asheville, N. C., August, 1887, 28.6; Newport, Ark., April, 1886, 21.2; Portland, Ore., December, 1882, 20.1 inches.

There is scarcely any locality in the United States where rain to the amount of two inches does not occasionally fall in a single day, while a fall of one inch is not unusual. The most excessive daily rainfalls are as follows:

Syracuse, N.Y., June 8th, 1876, eight inches; Melissa, Tex., April 22d–23d, 1879, eight inches; Helena, Ark., June 7th–9th, 1877, twelve inches, measured in forty hours, and as much more said to have been lost; New Haven, Conn., August 8th–9th, 1874, 8.7 inches; Hatteras, N. C., August 23d, 1880, 9.1; New Orleans, La., April 7th–8th, 1880, 9.2; Fort Wallace, Kan., June 22d–23d, 1874, 9.3; Mayport, Fla., September 21st, 1885, 9.5; September 29th, 1882, 13.7; Savannah, Ga., August 5th–6th, 1872, 9.6; Memphis, Tenn., June 8th–9th, 1877, 9.7; Healdsburg, Cal., April 20th–21st, 1880, 9.7; Fort Barrancas, Fla., August 29th, 1878, 9.8; Brownsville, Tex., September 21st–22d, 1886, 11.9; September 21st–23d, 23.14 in 64½ hrs.; Pensacola, Fla., June 28th–29th, 1887, 10.7; Brackettville, Tex., October 2d, 1881, 11.0; Lambertsville, N. J., July 16th, 1865, 12.1; Point Pleasant, La., April 5th, 1885, 12.3; Upper Mattole, Humboldt County, Cal., January 29th, 1888, 6.0; 30th, 8.5; 31st, 10.5 inches.

The most remarkable rainfall recorded in the United States during twenty-four hours is that which occurred at Alexandria, La., June 15th–16th, 1886, when 21.4 inches fell. This *down-pour* was not entirely local, since 13.3 inches fell during the same time, a few miles to the southeastward, at Cheneyville. At Tridelphia, W. Va., on July 19th, 1888, at the time of excessive local floods, 6.9 inches of rain were said to have fallen in fifty-five minutes. In any event the local rainfall was enormous, as evidenced by the suddenness and severity of the floods.

Excessive as these heavy rainfalls may appear, they are exceeded in India, where, however, the same peculiarity obtains as in the United States; the heaviest daily falls not occurring in the same localities, as do the heaviest monthly rains. Blanford's reports show that at Delhi, 19.5 inches fell September 26th, 1875; at Rewah, 30.4, June 6th, 1882; at Nagina, 32.4, and at

Purneah, Bengal, on September 13th, 1879, the unprecedented amount of thirty-five inches was recorded.

The following extraordinary showers, which, in lieu of any better term, may be called *down-pours*, indicate the portions of the United States where most excessive rainfalls, of rates ranging from five to eighteen inches per hour, may be occasionally expected.

Washington, D. C., June 27th, 1881, 2.34 inches in 37 minutes; Philadelphia, Pa., July 26th, 1887, 0.62 inch in seven minutes; St. Louis, Mo., August 15th, 1848, 5.05 inches in one hour; Fort Scott, Kan., October 2d, 1881, 1.80 inches in twenty minutes; Osage, Ia., August 26th, 1881, 1.40 inches in fifteen minutes; West Leavenworth, Kan., July 21st, 1887, 1.90 inches in twenty minutes; Indianapolis, Ind., July 12th, 1876, 2.40 inches in twenty-five minutes; Alpena, Mich., September 20th, 1884, 1.05 inches in eleven minutes; Amanda, Ia., July 31st, 1878, 1.56 inches in fifteen minutes; Fort Randall, Dak., May 28th, 1873, 1.56 inches in fifteen minutes; Albany, N. Y., July 10th, 1876, 1.12 inches in ten minutes; Portsmouth, O., June 22d, 1851, 1.75 inches in fifteen minutes; New York City, July 27th, 1873, and July 17th, 1877, 0.50 inch in five minutes; June 5th, 1885, 0.30 inch in three minutes; May 22d, 1881, 1.15 inches in ten minutes; November 18th, 1886, 0.25 inch in two minutes; Huron, Dak., July 26th, 1885, 1.30 inches in ten minutes; Biscayne, Fla., March 28th, 1874, 4.10 inches in thirty minutes; Newtown, Del. Co., Pa., August 5th, 1843, 5.50 inches in forty minutes, and thirteen inches in three hours; Collinsville, Ill., May 23d, 1888, 1.70 inches in twelve minutes; Sandusky, O., July 11th, 1879, 2.25 inches in fifteen minutes; Embarrass, Wis., May 28th, 1881, 2.30 inches in fifteen minutes; Washington, D. C., July 26th, 1885, 0.96 inch in six minutes; Paterson, N. J., July 13th, 1880, 1.5 inches in eight minutes; Galveston, Tex., June 4th, 1871, 3.95 inches in fourteen minutes; Fort McPherson, Neb., May 27th, 1868, two showers, one of 1.50 inches in five minutes, and the other, 2.25 inches in forty minutes;

Concord, Pa., sixteen inches in three hours, and Brandywine Hundred, Pa., August 5th, 1843, ten inches in two hours.

The quantity of rain which falls during twenty-four hours, while not a certain index of the entire rainfall accompanying severe storms, gives, however, a good idea of the maximum amount. The meteorological conditions under which enormously heavy rainfalls occur are such that their prolonged continuance is quite unlikely; so that storms are rare where fully seventy-five per centum of the rain does not fall in a single day.

Among notable storms of rain may be mentioned that in New England from February 11th to 13th, inclusive, 1886. During this storm, as estimated by Professor Upton, five inches or more of rain fell over nearly 5000 square miles, and exceeding seven inches, occurred over 1500 square miles. During this storm the following amounts of rain fell: *Connecticut:* Hartford, 8.43; Colebrook, 8.44; New London, 8.93; Middleton, 9.37; Canton, 12.35. *Rhode Island:* Providence, 8.13 inches.

CLOUD-BURSTS.

Apart from even exceedingly heavy showers or down-pours may be classed the enormous masses of water which now and then fall, and which are popularly known in America as cloud-bursts or water-spouts. In such cases the amount of water that falls in an hour or two must equal rainfalls which are otherwise deemed excessive for a day or even for a month in the region. These down-pours of torrential rain are fortunately local, and yet more fortunately prevail in the less densely populated portions of the country.

Since the condensation of the entire moisture from the atmosphere, even when entirely saturated at 60°, would produce less than two inches of rain, it follows that an enormous amount of moist air must be drawn from adjacent regions, in order to render the conditions possible for such excessive precipitation.

August 17th, 1876, at Fort Sully, Dak., the heaviest rainfall ever known occurred ; and on the opposite side of the river (Missouri), the water draining from a cañon was reported to have moved out in a solid bank three feet deep and 200 feet wide ; August 26th, 1876, near Hay's City, Kan., a water-spout burst over Kill Creek, causing destructive floods ; August 31st, 1876, on Chalk Creek, Utah, five miles from Coalville, a cloud-burst was reported, and a solid bank of water, between three and four feet high, came down the stream, destroying dams, etc. September 12th, 1877, at Colorado Desert, Cal., during a heavy thunderstorm between Pilot Knob and Cactus, a water-spout burst, destroying 400 feet of railroad-track. November 16th, 1877, at Red Bluff, Cal., after a severe thunderstorm, attended by hail, a water-spout was observed. The stream of water was distinctly visible, and continued for about fifteen minutes, when it gradually disappeared. This occurred over the open country, and caused a stream of water ten to fifteen feet in a ravine where water is unknown except during heavy rains.

June 12th, 1879, on Beaver Creek, ninety miles south of Deadwood, Dak., there was a cloud-burst, which, without a gradual rise of water, in a few minutes covered the country and drowned eleven persons.

At Seven Star Springs, Mo., a cloud-burst occurring in hills above town on June 11th, 1881, carried away houses and drowned five persons.

On June 22d, 1884, a cloud-burst occurred near Jefferson, Mont., causing a body of water eight feet deep to rush down on the town. Three persons were drowned and one quarter of a mile of railroad track was washed away.

A cloud-burst on June 10th, 1884, in Humboldt Mountains, flooded valleys near Rye Patch, Humboldt Co., Nev., and badly damaged the Central Pacific track for thirty miles.

On June 8th, 1885, a cloud-burst broke above Pason de Cuarenta, Mexico, practically destroying the whole town and drowning more than 170 persons out of its 800 inhabitants.

It is probable that cloud-bursts must have occurred near Pittsburg, Pa., the night of July 25th–26th, 1874, when 134 lives were lost, and property valued at $500,000 was destroyed.

July 26th, 1885, near Pike's Peak, a cloud-burst with hail-storm, flooding a small portion of Colorado Springs and drowning two persons.

Near Wickenburg, Ariz., a cloud-burst, causing the Hassayampa River from being perfectly dry at sunset, August 6th, 1881, to be a stream a mile wide at 11 P.M., and from two to fifteen feet deep; in thirteen hours the river was again dry.

On August 8th, 1881, a cloud-burst occurred at Central City, Col., causing suddenly a stream of water from four to six feet in two streets.

The frequency and average daily amount of rain are quite important climatic characteristics, since in some localities the rain falls infrequently and in heavy showers, while at other places the rain falls often and in moderate amounts. For instance, the average amount of precipitation on each rainy day is 0.25 inch of water at Milwaukee, 0.21 inch at Rochester, N. Y., 0.19 inch at Pensacola, Fla., and only 0.12 inch at Poplar River, Mont.

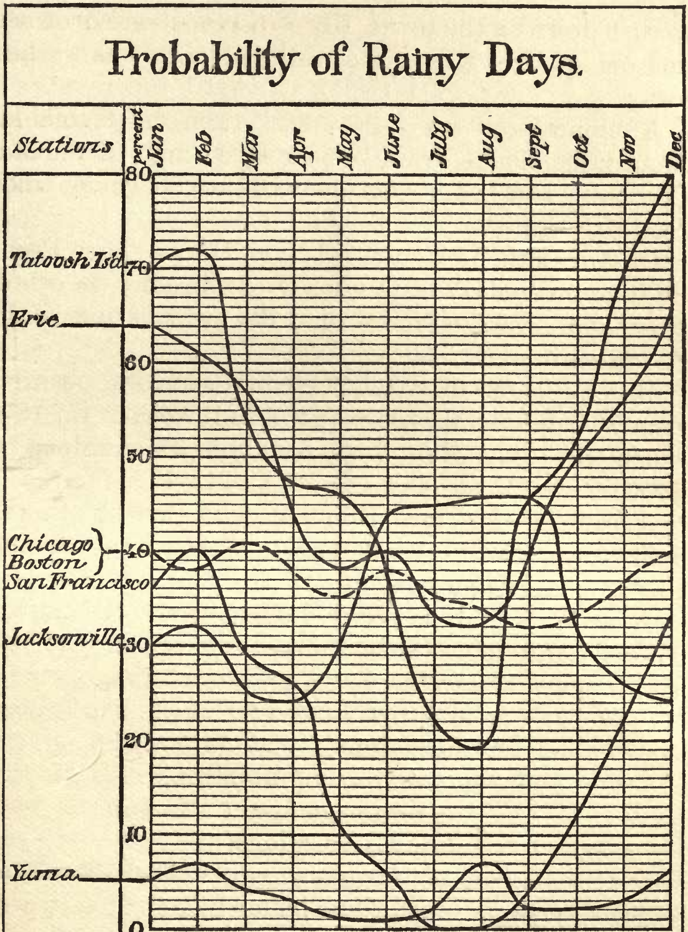


FIG. 24.

The distribution of rainy days throughout the year is graphically shown in Fig. 24. The calculated percentages of each month, thus charted for selected stations, make apparent at a glance the comparatively dry and wet periods of the various districts of the United States.

From the Missouri Valley eastward the number of rainy days during the year varies generally from 100 to 140, exceeding the latter number only in the lake region; especially along the southern shores of Lakes Erie and Ontario, where the number of days is as large as 171 at Rochester and 177 at Erie. The largest number of days occurs on the southeast side of the lakes, showing the influence of the prevailing westerly winds in bringing rain. North Volney, N. Y., with a yearly average of 195, has probably the largest number of rainy days of any place in the eastern part of the United States. There are but 134 rainy days at Milwaukee, against 152 at Grand Haven; 136 at Toledo, against 169 at Buffalo. The number of rainy days increases steadily from the Missouri and Mississippi valleys and the Gulf and Atlantic coasts toward Lake Erie. Over the Rocky Mountains and the plateau regions the number of such days ranges generally from seventy to ninety. On the Pacific coast it rapidly increases northward from forty-two at San Diego to sixty-six at San Francisco, 186 at Tatoosh Island, 224 at Sitka, and the astonishing number of 250 at Unalaska. The lower drainage basin of the Colorado Grande, the southeastern portions of California, and the southern part of Nevada show a remarkably small number of rainy days, there being but twenty-two at Keeler, Cal., and the minimum number of thirteen at Yuma, Ariz.

The average number of rainy days is, for each month, at selected places, shown in Fig. No. 24, from which it appears that at San Francisco the probability of rain sinks steadily from a maximum of .40 in February to less than .01 in July and August. The curve at Tatoosh Island is similar in character, since its maximum occurs in winter—.80 in December, and the minimum of .19 in August. The chances of rainy weather in the lake region are represented by the curve for Erie, the summer minimum and winter maximum being clearly outlined. The Jacksonville curve is peculiar in that the probability of a rainy day increases during the summer, being about .45 from June to September, inclusive, and sinking to a minimum of .43 in December and April, with an intervening secondary maximum in February. The chances of rainy weather in the country from the Mississippi Valley eastward varies but little during the year, except in the lake region, as shown by the Erie curve. Boston and Chicago are so closely in accord that their means have been consolidated, and they are represented by one curve, which varies less than two per centum for any month in the year from either mean. The probability of rain on any day in March is .41 at these places, while that for September is but .32, showing how fine and free from rain is the autumn weather. The Yuma curve is interesting, with its double maximum, in February and August, of .08 only, and its double minimum of .02 in October and .01 in May and June.

The variability of rainfall is an important question for all agricultural interests, since an annual rainfall of twenty inches may mean a fall of thirty inches for several years, followed by years of fifteen inches or less.

Blanford points out that in India a province is liable to severe famine, and consequent drought, if with an annual rainfall under fifty inches its mean annual deviation exceeds twelve per centum, in excess or defect.

Blanford's method of determining the mean annual deviation, while not free from objection, is used by the author for the sake of uniformity. Instead of striking a mean from the sum of all departures, whether plus or minus, he calculates a mean from the excesses and another from the minus departures, and takes half these averages as the mean annual deviation.

The following table shows the mean annual deviation of rainfall at certain selected stations which are fairly representative of different sections of the United States:

Years of Observation.	Stations.	Mean Annual Rainfall.	Deviation.	Per Cent. of Mean Annual Deviation.
59	Troy. N. Y.........	36.31	4.96	14
17	New York City.	43.86	4.5	9
17	Washington City....	43.84	6.76	15
16	Jacksonville, Fla....	57.15	5.32	9
17	New Orleans, La....	63.82	5.34	8
16	Nashville, Tenn.....	52.10	6.06	12
17	Detroit, Mich.......	33.57	6.00	18
17	St. Louis, Mo.......	38.56	5.60	15
16	St. Paul, Minn......	28.63	4.08	14
17	Omaha, Neb........	34.68	7.10	20
16	Denver, Col.........	14.90	2.39	16
16	Portland, Ore.......	51.65	6.72	13
10	Sacramento, Cal.....	21.73	5.38	25
16	San Diego, Cal......	10.81	4.08	37
11	Yuma, Ariz.........	2.92	1.37	47

It is noticeable that the percentage of deviation is exceedingly small along the Atlantic sea-coast and on the shores of the Gulf of Mexico. This small variability is a reliable indication that such sections are free from prolonged and disastrous droughts. Even as far west as the Mississippi Valley the deviation is small, rarely exceeding fifteen per centum, and at Denver is but sixteen per centum, showing a constancy of rain conditions not often credited to that section of the country. In the Pacific coast region the variability of the rainfall is greater than obtains in any other part of the country. In that section the rainfall is *seasonal*, the greater part of it falling in winter, so that the deviation is determined from the seasonal rainfall between July 1st and June 30th. The fall in the wettest year at Sacramento, where the deviation is twenty-five per centum, was 4.5 times greater than that in the least year, and at San Francisco six times. As a rule, the greatest deviation is found with a small annual rainfall, and Yuma, Ariz., with 2.92 inches a year, has a deviation of forty-seven per centum.

Blanford has carefully determined the hourly fluctuations of the amount of rainfall at Calcutta, from observations of seven years, 1878–84, inclusive. It has likewise been fixed by Draper for New York City, from observations during the seven years 1870–76, inclusive. The results of Draper's observations appear in Fig. 25, where the departures are charted. Both in Calcutta and New York the amount of rain is greater from noon to midnight than from midnight to noon. The fluctuations throughout the day are closely in accord at both places. The primary and secondary maxima fall at Calcutta from 5 to 8 P.M. and 2 to 5 A.M., and at New York from 4 to 7 P.M. and 2 to 5 A.M. The minima at Calcutta occur, primary from 10 to 12 P.M., secondary, 8 to 10 A.M.; at New York, secondary, 10 to 12 P.M., primary, 5 to 7 A.M.

The tendency is well marked at both stations for precipitation to occur in larger quantities after the air has passed its highest temperature and is cooling most rapidly, near and after sunset.

The question of the influence of vegetation and forests upon rainfall is a vexed one, and from its character is not susceptible of positive proof or disproof. The influence of forests on rainfall or temperature must depend on the extent, density, and character of the woodland growth. The evaporating and absorptive powers of foliage necessarily vary with the species, and are also dependent for nearly half the year on the amount of persistent leaves. There is no question but that the presence of vegetation subserves

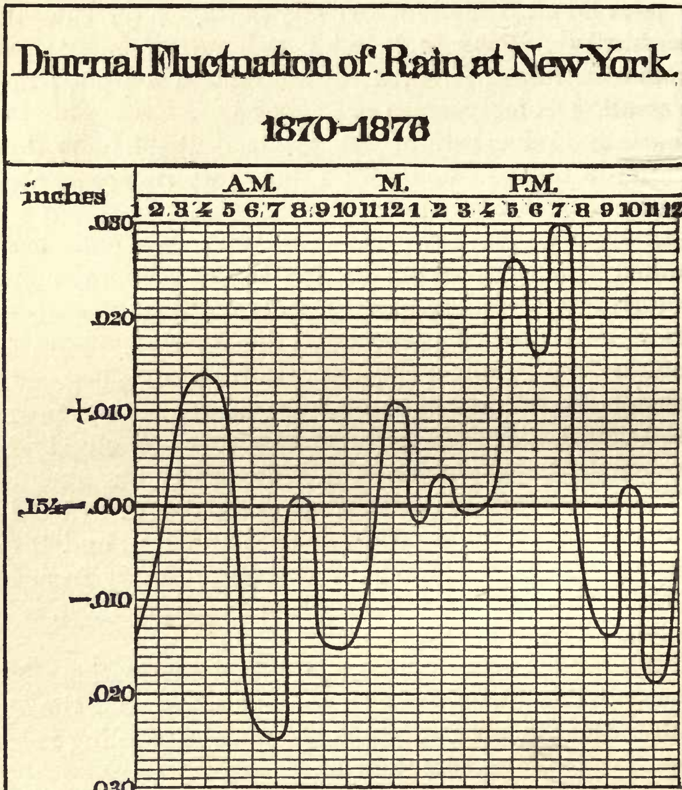


Fig. 25.

the conservation of rainfall and aids in its regular and systematic distribution. As has been intimated in treating upon dew, the amount of precipitation is increased in some sections to no inconsiderable extent by deposition in the form of dew upon the growing vegetation. Since the precipitation of a country is increased by the deposition of dew, and as the vegetation absorbs the moisture, instead of allowing it to pour into adjacent river-beds in rapid torrents, it necessarily follows that local evaporation is by this manner increased. While the amount of increase may be small in some cases, yet it must be considerable in others, and, as Blanford has pointed out, in India the rainfall in some sections is fed to no inconsiderable extent by local evaporation.

As regards the influence of forests, Woiekoff has pointed out that they assist in storing the water by protecting the soil, and thus maintain constant evaporation, and that the presence of the forests materially modifies the wind movement, thus preventing the transference of evaporated vapor to other points, while also tending to induce calms, which are so favorable to ascending currents and local precipitation.

The importance of this last condition is set forth by Blanford, who instances the heavy spring rainfalls of Assam, which result from direct diurnal convection of the humid atmosphere and its consequent dynamic cooling and precipitation.

Fortunately for elucidation of this question, the fire-devastated forests of the central provinces of India have within the past twelve years been replaced by extensive growth of young forests, covering 54,000 square miles. Twenty-two rainfall stations are maintained over this area, with records covering the past eighteen years. It appears from these observations that the rainfall for this province has progressively increased with the growth of the forest, and apparently is twenty per cent larger than the average for ten previous years. Observations in a forest in the Punjab, covering

17,000 acres, indicate, by a register within the forest, an excess of six per cent over the probable rainfall as computed from the rainfall registers of two stations, respectively, four and thirteen miles distant from the forest. While the evidence, as Blanford says, "is not rigorously conclusive," yet the author believes with him that the long-suspected influence of forests on rainfall is no longer a question of equally balanced probabilities.

Unfortunately, there are no such statistics available in the United States as in India, nor under as favorable conditions, but the writer believes that the extensive cultivation of the soil and the development of the Western territories has increased in some degree the rainfall west of the Mississippi River, through the medium of largely-increased vegetation and through the enormous increase of scrub growth, fruit and forest trees, which has resulted partly from the discontinuance of extensive prairie fires, and in greater part by the intelligent planting done by enterprising pioneers.

DISTRIBUTION OF SNOW.

The limitations of temperature are such that snow is practically impossible over two thirds the land surface of the earth. It is evident that snow may occasionally fall during very low temperatures in very low latitudes, but such phenomenon must be very rare in places where the mean temperature of the day does not sink for some portion of the year below 32°. The northern parallel of latitude at which snow never falls is not the same for all localities, but depends on elevation, nearness to the sea, and other causes.

The lowest latitude where snow has been known to fall on land of slight elevation is in the neighborhood of Canton, China, near the 23d parallel of N. latitude, within the tropics.

The United States is so situated, however, that snow occurs more or less frequently over almost the entire country. The southeastern part of Florida is the only portion of the country where this phenomenon has not been witnessed. Even as far south as Punta Rassa, Fla., within less than a hundred miles of Key West, snow fell for about five minutes on December 1st, 1876; and at San Diego, Cal., during the great snow-storm of January 15th–17th, 1882, snow flakes were for a short time seen descending. Although snow is thus possible over almost the entire country, yet it may be said to be practically unknown along the immediate California coast from San Francisco southward, and along the Atlantic coast from central Georgia southward. It occasionally occurs in considerable quantities on the Atlantic coast, even as far south as Savannah, and along the coast of the Gulf of Mexico, from Pensacola, Fla., to Brownsville, Tex. (25° 53′ N.). But in these sections it is not a phenomenon which recurs regularly year by year. It is a general rule that snow does not fall in sufficient quantities to lie upon the ground to the southward of the 33d parallel, except in mountainous and elevated places, nor within about fifty miles of the sea, as far northward as the 35th parallel on the east and the 38th parallel on the west coast.

The annual amount of snow is not constant for any locality, as it is dependent not only on the length and severity of the weather, but also upon the frequency and violence of atmospheric disturbances which cause precipitation. The newly fallen snow has a very small specific gravity, so that ten or twelve inches of it when melted are equal to only one inch of water.

The quantity of snow which falls annually over the northern half of the United States varies greatly from year to year, and, as a rule, decreases from Maine westward to the Rocky Mountain region. Assuming that the precipitation which occurs from December to February, inclusive, in the northern part of the United States is in the form of snow, it appears that the average annual snowfall may be placed at seven to eight feet in Maine, six to seven feet in New York,* four to five feet in Michigan, three to four feet in Iowa, two to three feet in Minnesota, one and a half to two and a half feet in Dakota and Montana, and from one to two feet in Wyoming and Nebraska. On the Sierra Nevada the average ranges from ten to thirty feet.

Among the remarkable snowfalls in extreme southern latitudes may be mentioned the storm of January 12th–15th, 1882, in the South Pacific coast region, when, in California, at Los Angeles, the hills about the city were white with snow, five inches fell at Riverside, three feet at Campo, and from four to fifteen inches from San Bernardino eastward to the edge of the Mohave Desert, and at a short distance inland from San Diego. The snow extended on the low hills in that region far southward into Lower California, Mexico (being twenty inches deep on the frontier), and in Arizona very heavy snow fell upon the desert to the westward of Tucson. It is probable that snow falls in these low latitudes only at very long intervals, since a similar storm has not been noted in those sections for nearly fifty years.

On January 27th–28th, 1880, in California snow fell at Gonzales for the first time in ten years ; at Salinas for the first time on record in the Salinas Valley ; at

* The snowfall in single years very largely exceeds the average. At North Volney, N. Y., 185 inches are reported to have fallen in 1856.

Los Angeles the heaviest ever known and for the first time in fourteen years, and through all Southern Arizona the snow was very heavy, with high winds.

On December 29th–31st, 1880, unusually heavy snow fell on the coast region bordering the Gulf of Mexico. There was five inches of snow at Montgomery, Ala., the most ever known, and nearly two inches at Rio Grande City, Tex., the first since December, 1866.

A somewhat similar storm occurred December 5th, 1886, when snow fell in considerable quantities at Charleston, Savannah, Mobile, and at Pensacola, Fla. Heavy snow, to the extent of about four inches, fell at New Orleans in 1852, in March, 1867, and January, 1881. At Shelbyville, Tenn., snow fell May 15th–16th, 1843, to the extent of fourteen inches.

The following are among the most remarkable monthly snowfalls in the United States, and from them may be fairly estimated the quantity of snow which may be called extreme during any month :

Cisco, Cal., March, 1882, 251 inches, and February, 1887, 228 inches ; Truckee, Nev., March, 1882, 120 inches, and Fort McDermit, Nev., January, 1885, 52.5 inches ; Palermo, N. Y., December, 1868, sixty-eight inches ; Marquette, Mich., December, 1884, sixty-seven inches ; Eola, Ore., December, 1884, sixty-one inches ; Strafford, Vt., February, 1887, sixty-one inches ; Port Angeles, Wash. Terr., February, 1887, forty-nine inches ; Rockford, Ill., March, 1887, forty-seven inches ; Worcester, Mass., January, 1882, fifty-three inches ; Quincy, N. H., February, 1887, fifty-one inches ; Wauseon, O., March, 1877, 41.7 inches ; Virginia City, Mont., December, 1879, 38.5 inches ; Cornish, Me. (in the woods), February, 1887, forty-eight inches ; Duluth, Minn., December, 1879, thirty-nine inches ; Greeneville, Pa., December, 1886, thirty-six inches ; Beloit, Wis., February, 1881, forty-two inches ; South Orange, N. J., December, 1872, thirty-eight inches ; North Colebrook, Conn., December, 1886, 38.5 inches ; Dover, Del., and Deer Park, Md., December, 1880, thirty-five inches ; Mount Solon, Va., December, 1880, twenty-eight inches ; Highlands, N. C., December, 1880, seventeen inches ; Montgomery, Ala., December, 1885, eleven inches.

Far the greater part of the snow falls from December to March, but occasionally heavy snowfalls are experienced in the northern sections of the United States during April and May. Even in June occasional light snowfalls have occurred, among which may be noted a general storm in Colorado, June 8th, 1884, and falls at Lynchburg, Va., June 12th, 1887, and June 11th, 1857. Near the end of July, 1883, snow is said to have fallen at Colebrook, Coos County, N. H.

Probably the most remarkable July snowfalls ever recorded are those of 1888, which were experienced in both the eastern and western hemispheres.

On the night of July 11th, 1888, slight falls of snow occurred locally over Great Britain, even as far south as the Isle of Wight in the English Channel. The day following heavy snow fell on Mt. Washington, N. H., reaching nearly to the base of the mountain.

CHAPTER XII.

THE WINDS OF THE UNITED STATES.

THE classification of winds by Dove into *permanent*, *periodical*, and *variable* has much to commend it. The northeast and southeast trades of the Atlantic Ocean are the best known of all the permanent winds. They are separated by a belt of calms, from four to eight degrees wide, which always remains north of the equator. For about twenty degrees of latitude to the north of this belt the wind blows almost without interruption from the northeast. The trades follow the sun northward and southward, lagging in the extreme phases of motion about a month behind it. It must be admitted that the steadiness of the trades as to force and direction is not as constant as once set forth. Variations of direction and interruptions are not unusual in the open ocean, and such modifications are quite decided near land.

The middle latitudes of both hemispheres, from about the 30th to the 50th parallels, have the anti-trades, permanent westerly winds, which in the Northern Hemisphere are materially modified on land by local and accidental causes.

The most important periodical winds are the winter and summer monsoons of Southern Asia, where from October to April the wind blows steadily from the northwest, and from April to October from the southwest. This periodical system extends from about thirty degrees north latitude, in Asia, southward to Northern Australia.

The interruption attendant on the reversal of the monsoon is called the "bursting of the monsoon," which, both in May and October, is often marked by violent hurricanes.

The term monsoon has been broadened in its meaning, so that monsoon winds signify those which recur with returning seasons. The attempt to apply the definite term monsoon to wind systems of other regions than Southern Asia has not gained general consent, and the author cannot agree with those who credit the United States with monsoonal winds.

The prevailing surface winds of the greater part of the United States are from southwest to northwest, and so are in substantial harmony with the upper wind currents, as shown by Mount Washington (N. W.), elevation, 6279 feet, and Pike's Peak (S. W.), 14,134 feet. The mean direction toward which the wind blows in the United States would not differ much from the average course of ordinary low-area storms—a little to the north of east.

South of the 31st parallel an opposite air current obtains, and in Florida the prevailing winds partake of the character of the northeast trades, being either easterly or northeasterly on the Florida coast, but as soon as they pass into the Gulf of Mexico and reach the land they veer to southeasterly or southerly. In this instance also it is to be remarked that the path followed by the wind is a parabolic one closely in accord with the course of the cyclonic (hurricane) storms of the Caribbean Sea. This relation of wind direction to the course of storms is worthy of note.

The passage eastward of storms developing in Saskatchewan, or along the eastern Rocky Mountain slope, naturally and fortunately tends to draw northward the moist winds of the Gulf. The presence of the

Rocky Mountain range aids in giving these winds a westerly component, and the slow rise in elevation not only gradually affects the course of the wind, but also condenses the moisture slowly, and so gives rain in sufficient quantity and with such equability as to make fruitful millions of acres of arable land, instead of pouring down torrents and drowning out a narrow fringe of coast region.

The prevailing winds to the eastward of the Mississippi River, excepting the Gulf States, are generally southwest to northwest. As exceptions may be mentioned the tendency during the summer months for winds, from Maine as far as Virginia to back to southerly, and from Virginia to Florida, to shift to northeasterly during autumn.

In the States bordering on the Gulf of Mexico the winds are, as a rule, from the south or southeast, although in winter there is a strong tendency in Texas for winds to shift to northerly. The Upper Mississippi and the Missouri Valley regions have winds according closely with the south or southeasterly winds of the Gulf States, except that in winter the southerly winds alternate with the northwesterly, the latter winds being somewhat more frequent.

Along the Rocky Mountain slope the winds of the northern portion are decidedly from the southwest, but elsewhere more frequently divided between two diametrically opposite points—south and north. The frequent development of low areas in Saskatchewan induce the former winds, while the movement of high areas southward from the same region produce winds from the opposite quarter.

In the Pacific coast region the country is so broken and of such constantly varying elevation that winds are largely local. The predominating coast winds are westerly, while inland the tendency is to southerly breezes.

The United States, in certain districts, are also liable to dry, hot winds, which have at times an important effect on the weather in producing for their localities prolonged periods of dry weather, known as hot terms. The best known of these are the easterly winds which blow from the interior of California toward the Pacific Ocean, and which in Southern California are known as the *desert winds.* Winds of like characteristics are experienced in northeastern Dakota along the Missouri River, where they blow from the *bad lands* situated to the south or southwest. Similar to these are the *scirocco* winds of the African coast, which come from the African deserts, and which reaching Spain as southeasterly are there known as the *leveche.* In Egypt the desert wind is popularly supposed to blow for fifty days, and is consequently called *Khamsin.* On the West African coast this desert wind is known as *Harmattan.*

Apart from these dry, hot winds, which come from the land, should be mentioned another special class, known as the *Foehn* winds. This wind, first studied and explained in Switzerland by Hann, where it is called the *Foehn*, gives its name to similarly heated winds in other parts of the world.

The warm winds to the eastward of the Cascade range, in Idaho, Washington, and Montana territories, known as the Chinook winds, are in part Foehn winds. In a like manner these winds occur occasionally to the westward of Greenland, and under favorable conditions in South Africa, Australia, New Zealand, and Peru. It doubtless occurs that in many cases in the United States these *chinook* winds are brought by atmospheric circulation from a more southern and warmer region, and retain in their northerly course a portion of their original heat, but in general their abnormally high temperature is to be attributed to similar causes which induce it in the Foehn winds.

Dry air in passing over a mountain range would not differ in temperature on the two sides of the range. As the air ascended it would be cooled dynamically. As it descended it would be warmed just as much. But if the air is moist, in ascending it cools, and the moisture is condensed and falls as rain. The latent heat released by the condensation raises the temperature of the air, and in descending the other side of the mountain it is warmed up dynamically still more. This is the action of the Foehn wind and the explanation of its warmth and dryness.

The *northers* of the United States are dry, cold, strong winds from the north, which are generally preceded by high, warm southerly winds. Similar disagreeable and violent cold winds are experienced in many other regions, all resulting from abnormal distribution of atmospheric pressure. Among these may be mentioned the well-known *mistral*, a northwest wind which blows from Eastern and Central France down on the Mediterranean along the Riviera; the northeasterly *gregale* of Malta, the northerly *tramontana* of the Adriatic, and *bora* of Trieste and Dalmatia.

The *norther*, when violent and the air is filled with drifting snow, is known in the United States as a *blizzard*, in the Yenisei Valley as the *purga*, and on the steppes of Central Asia as the *bura*.

In the Southern Hemisphere the southerly *buster* occurs in New Zealand. The southwesterly *pampero* in Uruguay and the southeast winds on the Punos are also cold dry winds of similar origin.

The prevailing direction of the wind does not absolutely show the actual movement of the atmosphere at the station, since winds blow with variable force. An

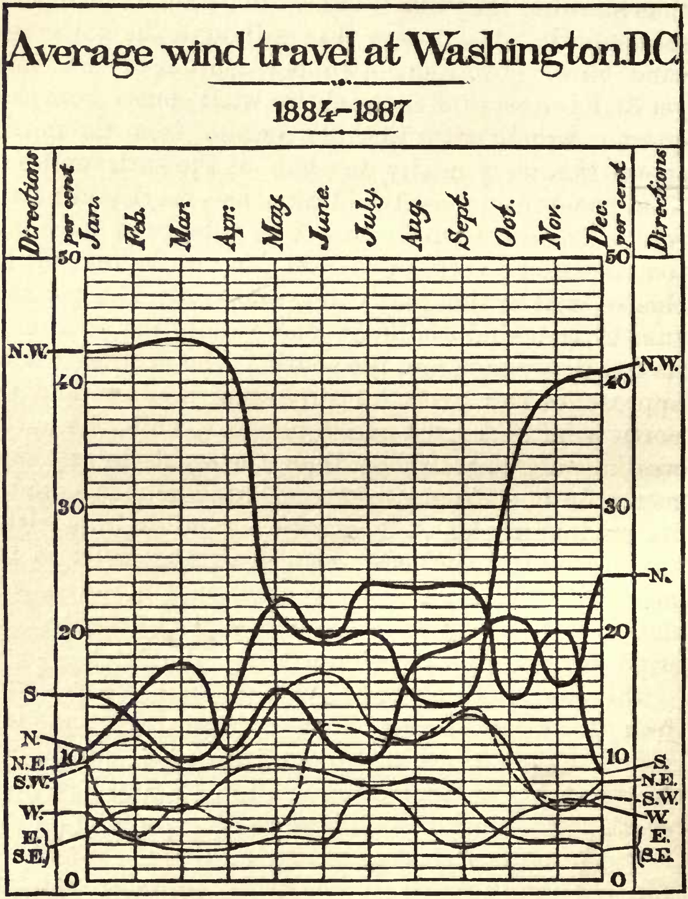


FIG. 26.

examination of the records of wind direction and velocity for Washington City for the four years ending

December 31st, 1887, gives data for separating the actual miles of wind from the eight principal points of the compass, which appear in Fig. 26 in percentages, thus showing the wind's translation proportionally for each month. It appears that although the northwest wind blows but twenty-two per centum of the time, yet 31.1 per centum of the entire wind comes from that quarter, which, with 15.6 per centum from the north, shows that very nearly one half of the entire miles of wind come from these two directions—north and northwest. The south winds prevail in mileage at Washington, as will be seen, only from May to September, inclusive, and in the yearly aggregate only 17.2 per centum of the wind's mileage and twenty per centum of its frequency are from the south. The northeast wind approaches the south in percentage in June and the north wind in August and September, while the northwest is only slightly less than the south in any summer month, so that no summer wind is monsoonal in its predominance. The number of miles from either the east or the southeast is so small and differ so immaterially from each other that they were consolidated, each comprising about five per centum of the wind translation at Washington.

The average velocity in miles per hour of the wind from the different quarters, determined from these four years' observations at Washington, is as follows: North, 5.7; northeast, 5.2; east, 4.6; southeast, 4.7; south, 4.8; southwest, 5.1; west, 4.9; northwest, 8.6.

Put forth as a general statement, it may be said that for the United States the monthly period of wind velocity finds its maximum in March or April and its minimum in August.

As given by Scott for Armagh, Ireland; Liverpool, England; and Sandwick, Orkney, the maximum and minimum wind phases for Great Britain seem to fall respectively in January or February and in June or July.

Previous to the use of self-registering anemometers, it was only known that winter and spring winds were usually higher than those of summer and autumn. Records of the past ten years show, as a general rule, that for the United States the mean monthly wind velocity, when charted for the year, is expressed by a curve with a single inflection, the decrease to the lowest, and increase to highest being regular and unbroken.

The average velocity of the wind varies quite materially from month to month, the highest mean monthly velocity at any place averaging for the United States, as a whole, about fifty per centum above the least. The differences are greater at coast stations than inland, as can be seen from Fig. 27. Both San Francisco and Eastport experience one hundred per centum more of wind in the maximum month than in that of the least velocity. For the greater part of the country the average velocity of summer winds is between five and eight miles per hour, which increases from December to March to velocities between eight and twelve miles hourly.

The following figure, No. 27, shows the fluctuations through the year of the mean monthly velocity of the wind for Eastport, Me.; New York City; Cincinnati, O.; Nashville, Tenn.; Dodge City, Kan.; San Francisco, and San Diego, Cal.

In the United States, eastward of the Mississippi, the highest mean velocity, generally speaking, occurs in March, as shown by the curves for Eastport, New York, and Cincinnati, while to the westward it most frequently obtains in April. There are some local ex-

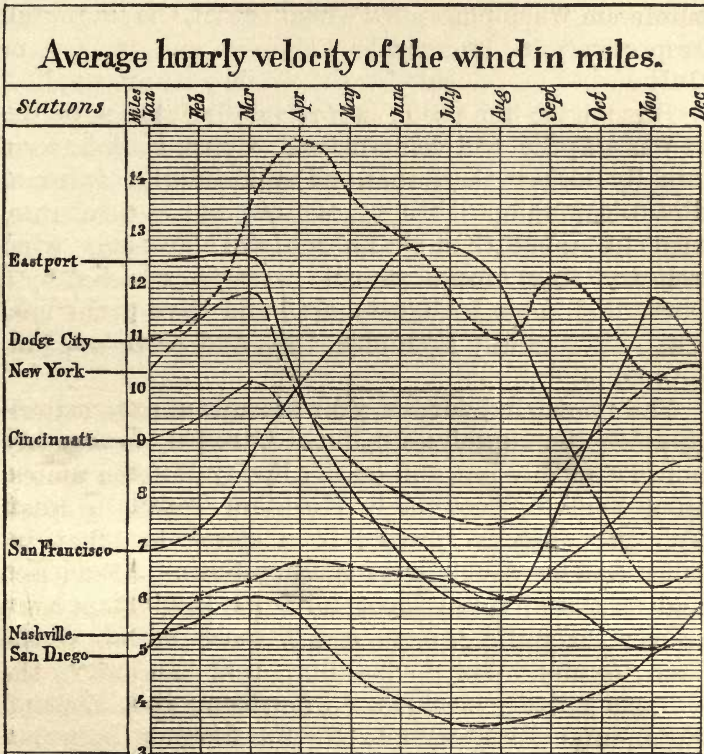


FIG. 27.

ceptions to this rule, the most marked being the high winds of November and December at certain stations on the great lakes. In the Pacific coast region the winds are not quite so regular, being highest during January and February on the north Pacific coast, and in June and July on the middle Pacific, as is shown by the curve for San Francisco.

The lowest monthly velocity to the eastward of the Rocky Mountains occurs in August, with but few exceptions. To the westward of the mountains, save along the Washington and Oregon coast, the least wind is in November or December.

The wind movements for the whole year are smallest at places in the Ohio Valley, in the interior of the south Atlantic and eastern Gulf States, in Arkansas, Idaho, Southern California, and in the interior of Oregon and Washington Territory, the average hourly movement being less than six miles in the above-mentioned regions. The lowest annual averages are those of Nashville, Tenn.; Augusta, Ga., and Olympia, Wash. Terr.—four miles; Roseburg, Ore., and Lewiston, Ida. —three miles.

The most wind for the year prevails at exposed stations on the New Jersey, North Carolina, Texas, and north Pacific coasts, and on the Rocky Mountain slope from Eastern Montana to Northern Texas. Annual average velocities ranging from eleven to seventeen miles per hour obtain at such stations. Among the highest averages are those for Fort Maginnis, eleven miles; Dodge City, Kan., and Tatoosh Island, Wash. Terr., twelve; Indianola, Tex., and Sandusky, O., thirteen; Sandy Hook, N. J., fourteen; Block Island, R. I., and Kitty Hawk, N. C., fifteen; Delaware Breakwater, Del., sixteen, and Cape Mendocino, Cal., 17 miles. The exceptionally high velocities of this last station are due to its situation on very high land, 637 feet, directly overlooking the ocean.

The highest winds occur along the sea-coasts and lake shores, whence the velocity diminishes inland quite rapidly as the distance from the sea increases. One notable exception, perhaps the most remarkable in the world, is the wind system of the region extending southward from Eastern Dakota to Northern Texas, over which exceedingly strong winds prevail both summer and winter. This is explained by the physical configuration of the country, a uniformly descending plain, sparsely covered with vegetation and unbroken by mountains or even high hills for a thousand miles, from Montana to the Gulf of Mexico. The Ozark and other small mountain ranges partly protect Missouri and Arkansas, by diverting to the westward both the warm southern cyclonic winds from the Gulf of Mexico and the cold outpours of cold air from Saskatchewan or Manitoba.

In Fig. 28 is shown the mean relative velocity of the wind for each hour of the day for March, as determined from four years' observations at important points in the United States. This month is selected as a characteristic one, since its mean hourly velocity is greater, as a rule, for the United States than that of any other month. Almost without exception the highest mean velocity occurs at 2 or 3 P.M.—that is about the hour of the highest temperature of the day. The lowest hourly velocity obtains at hours varying from 4 A.M. to 6 A.M. But in certain localities there are marked exceptions to this rule. For instance, at Cheyenne the wind reaches its minimum at 10 P.M., and increases steadily to a maximum at 1 P.M. At Atlanta, Augusta, Chattanooga, and Charleston the least wind occurs about 7 A.M. If, as appears strikingly evident from Figs. 20 and 28, the velocity of the wind largely depends on the ascending or descending currents set in motion by the heating of the air or radiation of the earth, it would be expected that the hours for the least wind would be somewhat indefinite.

A very marked exception to this rule is shown by the records at Block Island, an island off the coast of Rhode Island, where general inflection of the curve, as will be seen, is in direct opposition to the land curves, the maximum obtaining at 5 A.M. and the minimum

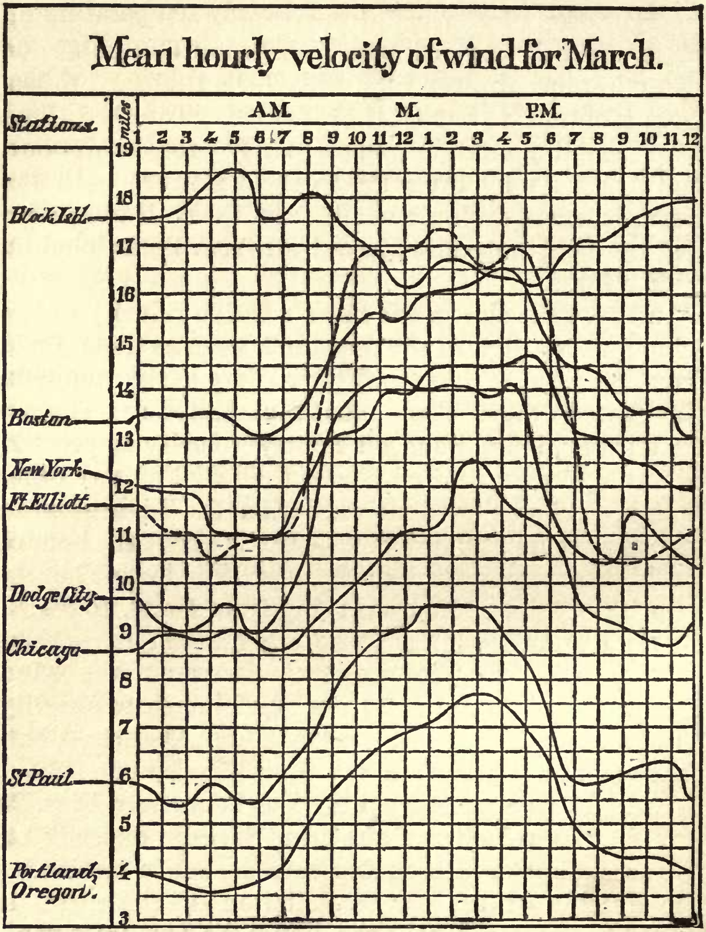


FIG. 28.

from noon to 5 P.M. Nearly the same thing occurs at Thunder Bay Island, Lake Huron, where the maximum occurs at 2.30 A.M. This may be a climatic characteristic of islands near mainland.

The regularity with which the mean hourly velocity of the wind follows the mean hourly temperature of the air is strikingly evident by comparison of Figs. 20 and 28. The variation in the mean velocity of the wind from hour to hour is very great, since, as a rule, the velocity is from forty to seventy per centum greater at the hour of its maximum than at the hour of least velocity. At certain stations where the mean wind velocity is small, the increase is even greater, being in some localities over one hundred per centum, as is shown by the curve for Portland, Ore.

During the winter months the wind, as has been pointed out, is of greater velocity than in the summer months, and occasionally the mean hourly velocity of the wind for an entire month has been excessively great. Among the most striking instances which will serve to illustrate the excessive phase of this phenomenon in the United States are the following: Mount Washington (elevation, 6279 feet), during January, 1885, the mean hourly velocity was forty-nine miles per hour throughout the month, and in February, 1883, forty-eight miles; Pike's Peak (elevation, 14,134 feet), December, 1886, thirty-two miles; Cape Mendocino (elevation, 637 feet), November, 1885, twenty-nine miles; Sandy Hook, December, 1885, and Cape May, March, 1887, twenty-two miles; Cape Hatteras, March, 1883, twenty miles; Tatoosh Island, January, 1886, nineteen miles; Fort Shaw, Mont., February, 1882, eighteen miles; Cheyenne, Wyo., February, 1886, Rochester, N. Y., February, 1883, and Dodge City, Kan., March, 1884, seventeen miles per hour for the entire month.

In marked contrast to these excessive velocities for long periods is instanced the wind movement at Lewiston, Ida., for November, 1884, when the velocity was but 0.4 miles per hour.

As very remarkable wind storms which lasted for long periods may be quoted that of Mount Washington, February 27th, 1886, when the mean hourly velocity for twenty-four hours was 111 miles, and at Yankton, Dak., April 13th, 1873, when the mean hourly velocity for the twenty-four hours was about fifty miles.

The maximum velocity of the wind in the Signal Service has been usually obtained from the rate for fifteen consecutive minutes, and the following extreme velocities referred to have been determined in like manner: By this method it appears that the highest winds ever recorded are, as a rule, between the limits of fifty miles per hour and seventy miles per hour for the sections of the United States between the Rocky Mountains and the Atlantic Ocean. In the Rocky Mountain districts and the Pacific coast region the velocity has very rarely exceeded fifty miles an hour. At Cape Mendocino a velocity of 144 miles was reached January, 1886; 104 miles at Fort Canby, December, 1884, and eighty-two miles at Portland, December 12th, 1882. The highest velocities for any section are those experienced along the middle and south Atlantic coasts. Winds ranging from seventy to eighty miles per hour have been occasionally recorded along the whole of this coast line. On the North Carolina coast velocities ranging from ninety to a hundred miles have several times occurred during cyclones from the West Indies. Among the most remarkable of these velocities may be quoted Sandy Hook, Cape May, and Cape Henry, eighty-four miles; Fort Macon, ninety-two; Southport, ninety-eight; Kitty Hawk and Cape Hatteras, 100 (the latter estimated); Cape Lookout, 138 miles. The last-named velocity occurred during the great hurricane of August 17th, 1879, when the anemometer blew away before the wind reached its maximum velocity.

On the summit of Pike's Peak the extreme velocity recorded is comparatively low, being 112 miles in June, 1881. Velocities exceeding this have not been infrequent on Mount Washington for many consecutive hours, and in January, 1878, the extraordinary velocity of 186 miles per hour occurred.

At Montreal, Can., on March 13th, 1888, the wind blew at the rate of 110 miles per hour for a single mile, but only at the rate of ninety for three miles—*i.e.*, for a period of two minutes only.

The velocity of gusts which have occurred during hurricanes and tornadoes undoubtedly exceed 100 miles an hour, and possibly, in view of the high velocities on Mount Washington, may even reach for brief periods the rate of 200 miles.

CHAPTER XIII.

STORMS.

THE author was some time since asked, "What is a storm? What do you mean when you say a storm is coming?" The definition then given may serve here. A storm is a decided or violent disturbance of the atmosphere, which undergoes translation from place to place. This disturbance may or may not be accompanied by precipitation, such as snow or rain, but the area of disturbance must move from point to point, and there must be a decided transfer of air, indicated either by strong surface winds or by marked changes of pressure, showing upper air currents—silent, but none the less efficacious.

Again, this atmospheric commotion may be general and widespread, the storm-centre travelling for days slowly across the whole country, with strong winds and moderate long-continued rain; or perchance a passing local thunderstorm with lightning and hail, which spends its force within narrow limits in a scant hour's time; or it may be a violent tornado with destructive winds cutting a narrow path a few hundred yards wide and a mile in length, its coming and going a matter of minutes. The main distinguishing feature is then the movement of the air—the presence of wind. In the United States we may consider as a storm such a disturbance as diverts the winds to a marked degree from their usual direction, while augmenting their customary force. As has been pointed out in the chapter on winds, the force of the wind varies largely each day, and also is not constant for different months. In general, it may be held that an increase in velocity twenty per centum above the mean indicates that the wind is a storm wind. Storm winds vary from 200 to 300 miles daily travel with freezing temperatures, or 300 to 400 miles at higher temperatures. Winds from twenty to thirty miles per hour are considered dangerous, according to the degree of cold and the amount and kind of attendant precipitation, or its total absence.

The severity of the disturbance is not always evidenced by the abnormally high or low reading of the barometer, the prevalence and amount of the precipitation, nor even by the violence of the winds—although this latter is generally a good index—but by the *barometric gradient.* This gradient indicates the change of barometric pressure in a given distance, and has at its unit of pressure .01 inch, and of distance fifteen geographical miles, measured perpendicular to the isobars.

As, for instance, a gradient of two means that under such condition in a distance of fifteen miles there is a difference of two hundredths of an inch between the reduced readings of two barometers.

It seems advisable that a thermometric gradient should be formulated, since it is a marked feature of certain strong, cold winds that they appear to depend almost entirely on difference of temperature in a given distance, as they occur with very feeble barometric gradients. It is suggested that the unit of such a gradient be one-tenth of a degree to a distance of a degree of a great circle on the earth's surface, which is sixty geographical miles.

The winds are, as a rule, proportional to the steepness of the gradient, and the tendency of cyclonic winds is spirally inward and upward toward the centre of barometric depression, the circulation being *contrary* to the motion of the hands of a watch.*

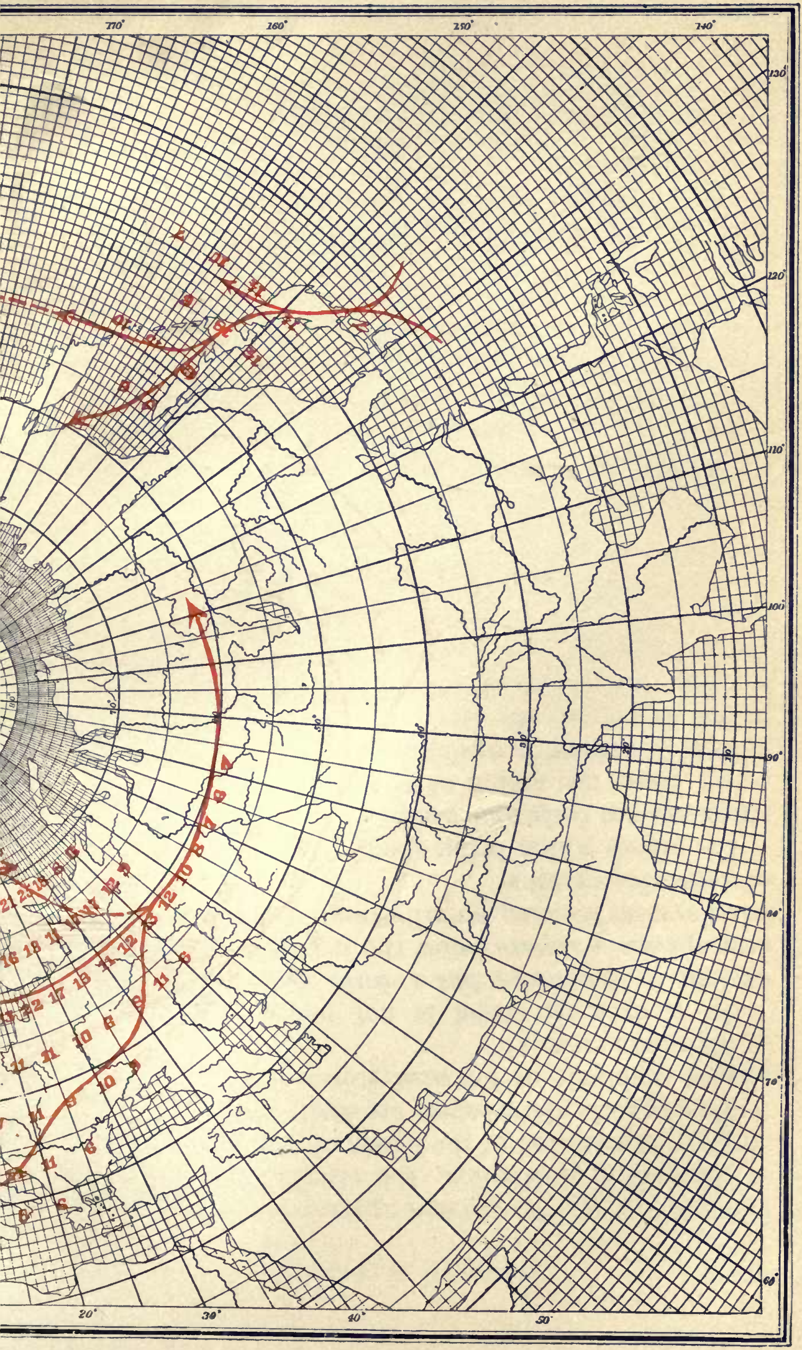
Atmospheric disturbances are easily divided into two classes—cyclonic or low-area storms and anti-cyclonic or high-area storms.

By a cyclonic storm is not necessarily meant a cyclone or hurricane, but a storm characterized by an atmospheric pressure below the average, and having a wind system blowing spirally inward, as do the winds of a genuine cyclone.

The causes which bring about a cyclonic or low-area storm are not fully and accurately known. That they result from the action of the sun in disturbing the general atmospheric equilibrium, by causing variations in the density of the air, is admitted, but beyond this opinion diverse theories obtain, and it is not probable the problem can ever be resolved with positive exactness. Although far the greater part of the action of all and the whole of some storms takes place within a mile of the surface of the earth, yet the movement of upper clouds and occasional attendant peculiar phenomena indicate quite clearly that the origin and most important phases of many violent atmospheric changes must be assigned to the upper strata of the air. It is well known that the abnormal conditions which characterize low-area storms often pass by Mount Washington without obtaining on its summit (6279 feet), and that low mountain ranges, such as the Allegheny or Blue Ridge, occasionally break up or materially modify the course and progress of such storms.

The formation of a depression or low area is prob-

* This applies to the Northern Hemisphere only, since in the Southern Hemisphere the movement is with the hands of a watch.


170°
160°
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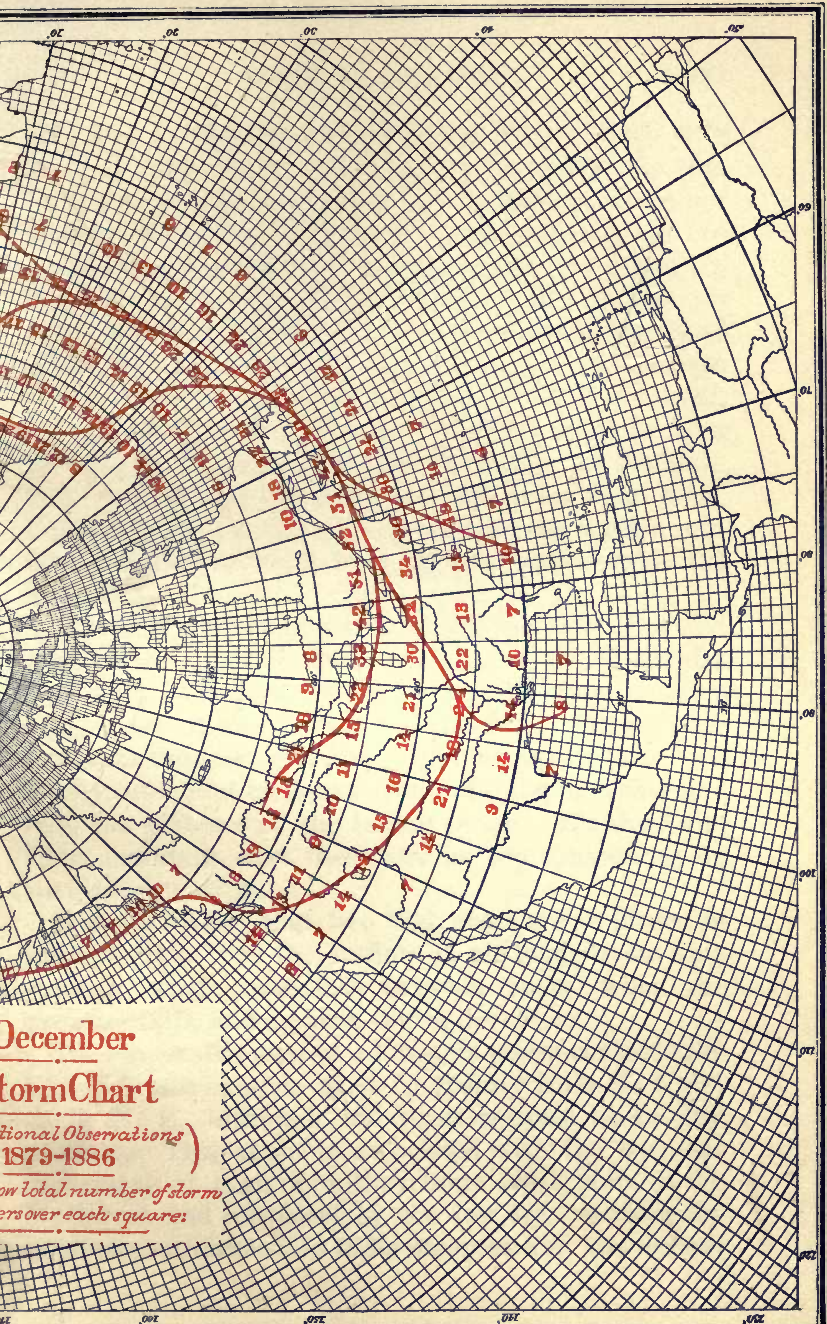
December
tormChart
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ow total number of storm
ers over each square:

ably due to precipitation or formation of cloud, or is at least very closely related in some way to the condensation of aqueous vapor. The motion of the low area probably depends on the prevailing direction of motion of the great body of upper air in the vicinity of the low. A current of air on the earth's surface, no matter in what direction, is deflected to the right hand of the direction in which it is moving in the Northern Hemisphere by the action of the rotation of the earth. A wind moving with a velocity of thirty miles an hour from south to north in latitude 40° north, for instance, will be deflected toward the east six miles in an hour, neglecting the friction of the wind on the earth's surface, the effect of which is to augment considerably the deflection.

The heavy rainfalls are probably the initiating and predominating cause, since cyclones of the Caribbean Sea, with attendant excessive precipitation, develop into severe storms before the deflecting force exerts any considerable influence. Similar results are evidently attendant on heavy local rainfalls in connection with the cyclones of the Indian Ocean. Blanford and Eliot maintain that these storms are consequent on such precipitation.

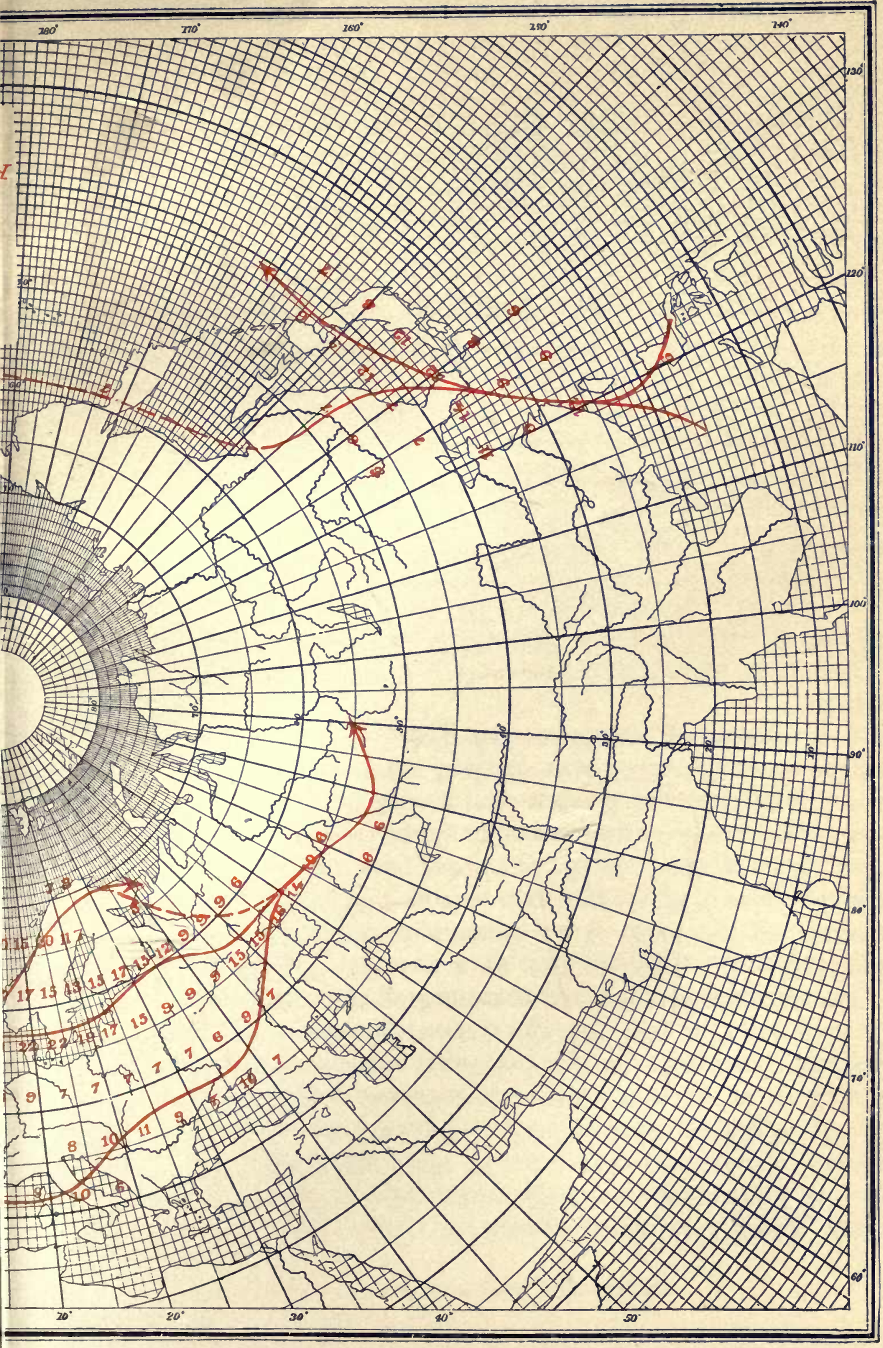
It again occurs that two high areas are so placed in juxtaposition that the outflow of air tends to set up a cyclonic wind circulation between them, when the pressure falls, and a storm-centre develops.

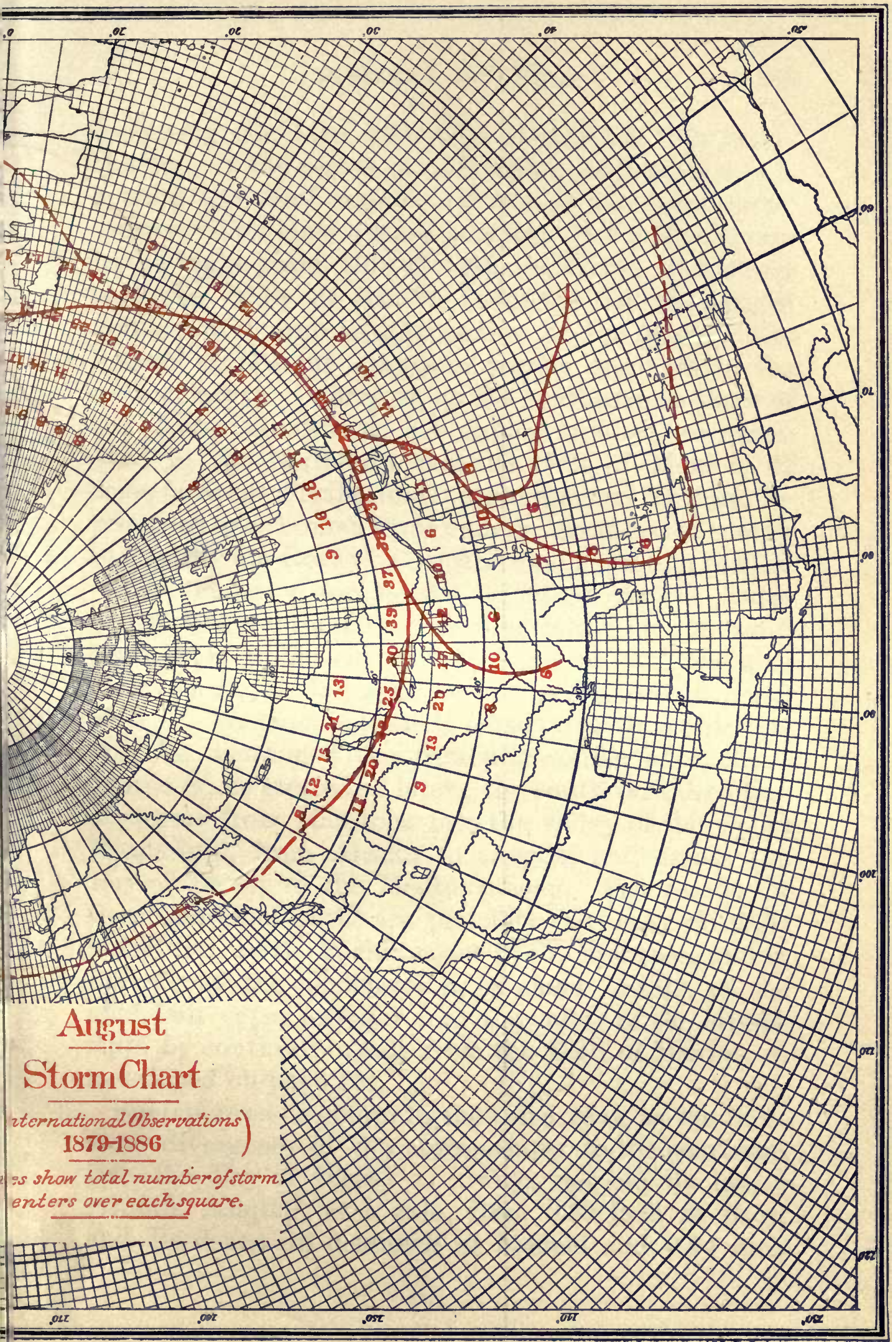
The largest diameter of a low-area storm-centre in the United States extends most frequently from W. S. W. to E. N. E., although its direction may be in any azimuth. This shape is associated with the frequent occurrence of high or anti-cyclonic areas both to the northwest and southeast of the low area, causing the gradients on these sides to be steepest and the isobars most crowded in these quadrants. This condition is so well known that a marked elongation of the storm-centre in the northwest part of the United States or on the Atlantic coast is held to indicate an excessive high area to the northwest and southeast, respectively, beyond the limits of the ordinary weather maps in British America and over the Atlantic Ocean.

Occasionally the isobars surrounding the centre of a depression are circular, but, as a rule, they approach nearest to the form of an elongated ellipse, in which the diameter of the longer axis is from 1.3 to 2.5 greater than the shorter. As the low areas pass from land to sea they become more regular in shape, the elongation being modified, and it often occurs that the depression at the centre becomes more marked, with a corresponding steepness of gradient and increased violence of winds.

The reason for irregularity of form in isobars on land is not definitely known, but since they disappear in part over the level expanse of the ocean, it is not unreasonable to suppose that these irregularities are due in large part to the physical configuration of the land over which they pass. The broken land surfaces modify materially the precipitation, and thus increase or diminish the influence of an important factor in the storm's progress—the latent heat given forth by the condensation of the indrawn vapor. The irregularity of the land interferes likewise largely with the free and full indraught of surface winds, which thus prevail unequally in different quarters, even when the gradient is uniform on all sides.

The frequency and usual tracks of low-area storms in the Northern Hemisphere are shown on Charts XX. and XXI., for the representative months of August and December, these months being selected as being re-





August
Storm Chart
nternational Observations)
1879-1886
es show total number of storm
enters over each square.

spectively the least and most stormy for this hemisphere. In the centre of each square of five degrees is entered the *total* number (*if six or more*) of storm-centres which have passed over any part of the square in the eight years, 1879 to 1886, inclusive. It appears that the valley of the St. Lawrence has the largest number of storms of any section of the globe. The greater number of American storms originate in the Saskatchewan country or on the southeastern slope of the Rocky Mountains. A minor number are developed in the Caribbean Sea, the Gulf of Mexico, or come from the Pacific, and it is not unusual for these depressions to be broken up or undergo great loss of energy in crossing the Rocky or Appalachian mountain ranges.

The tendency for storms to follow certain routes or to diverge therefrom is illustrated by the solid track lines on the charts. As has been said, the ultimate course of low-area storms is somewhat north of east. As most noticeable departures from this rule may be mentioned the parabolic course of cyclonic storms (to be treated of later), the southward direction of storms from Manitoba into the valley of the Upper Mississippi, from Alaska to Oregon, and across the Bay of Biscay to the Mediterranean. The reason for these abnormal paths are probably the heavy rainfalls along the north Pacific coast in the first case, and in the second the condensation, as cloud or rain, of the abundant vapor brought into the valley of the Mississippi by southerly winds from the Gulf of Mexico, as mentioned on page 164.

Similar reasons obtain in the third case, as the initiatory divergence of the storm-centre to the southeast into the Bay of Biscay is always marked by heavy rainfall, ranging, as a rule, from 0.39 inch at Brest and Bordeaux to 0.48 inch at Madrid and 0.94 inch daily at Lisbon. These conditions are also supplemented by a secondary cause, since at such times a high area with intervening steep gradients prevails over Sweden and Norway to the northeast, while a second high area is to the southwest over the middle Atlantic.

In general, but not invariably, land storms which travel slowly are less violent than those which move with great rapidity. The same causes that lead to violent fluctuations and increasing intensity near the storm-centres appear to favor rapid progression.

The number of well-defined low-area storms which cross the United States average eight in each month, from May to August, inclusive; nine from September to November, and in April; eleven in February, March, and December, and twelve in January.

Storms move more rapidly in the United States than elsewhere. The most rapid progression everywhere is in winter, about one half greater than in summer. The same ratio, it may be remarked, exists between the mean velocity of summer and winter winds of this country. The average velocity of low-area storms in the United States is twenty-five miles per hour from June to September, inclusive. It rises gradually to twenty-nine miles in October, thirty in November, thirty-five in December, and thirty-eight in January and February, whence it sinks to thirty-three miles for March and twenty-six miles per hour in April and May. It has been known for many years that the velocity of winter storms is greater than that of summer, but a careful examination of the velocity of storms during the past twelve years in the United States shows that the increase is regular and unbroken from September to February, and thence the decrease is regular to June.

It follows, then, that the fluctuation of the United States storms throughout the year, as to frequency and rapidity of movement, is accurately represented by approximately similar curves, which have but a single inflection, with the maximum frequency and rapidity in January and February and the minimum from May to August inclusive.

The movements of low areas in middle latitudes to the eastward evidently depend on the general drift of the atmosphere in that direction. As has been pointed out on page 164, the general direction of the surface winds does not differ very materially from the general course of low-area storms, although the direction of the latter is apparently affected to a considerable extent by the trend of the Ohio and St. Lawrence valleys, followed so often by the storm-centre.

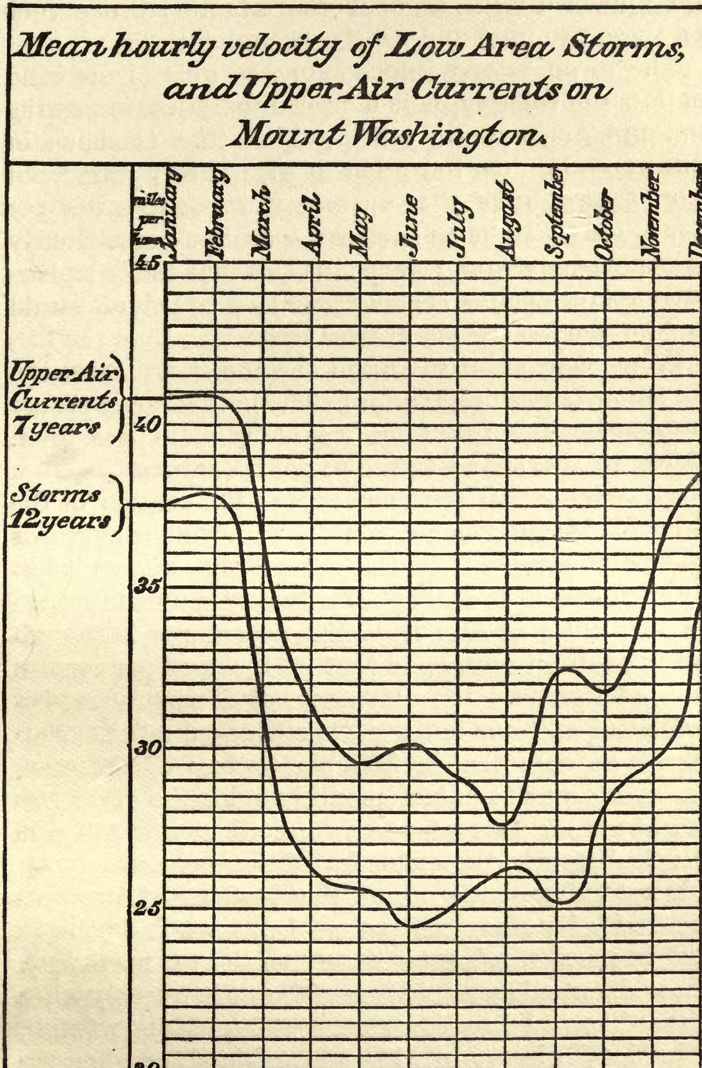
That the velocity of the surface winds is less than that at which storms move is what might be expected, since, owing to friction with the surface of the earth, these winds blow with much less velocity than the upper air currents. The interruptions of the regular westerly winds are not infrequent near the surface of the earth, but, as the observations on Pike's Peak and Mount Washington show, these interruptions are rare and of short continuance in the upper currents.

The hourly velocities of the wind for January and July, respectively, at these high stations are as follows: Mount Washington (6279 feet), about forty-one and twenty-nine miles; Pike's Peak (14,132 feet), twenty-five and twelve miles. The mean hourly velocity of low-area storms in January is 37.5 miles, and in July, 25.2 miles.

It thus follows that the mean velocity of the transference of storm conditions on the surface of the earth is not far from being equal to the mean movement of the upper currents, as deduced from the observations on these two high and widely separated peaks.

The mean hourly velocity for the year of the wind on Mount Washington is not accurately known, owing to large accumulations of frost on the anemometer during certain periods, but it can hardly vary, not more than a mile or two, from thirty-four miles per hour—only five miles greater than the mean hourly velocity of low-area storms; so that the latter apparently correspond to the movement of upper air strata in New England at about 6000 feet.

From personal investigation, the author is disposed to go further, and express his belief that the average movement of low-area storms, at least in the United States to the eastward of the 100th meridian, bears a direct relation to the velocity over this region of the upper air currents at, say, 6000 feet. It appears in this connection also more than probable that the movement of the upper currents must have a potent influence upon the direction of motion of the storm-centre, although it does not necessarily follow that the storm-centre should move exactly in the same direction as the upper currents, but rather there should be deflections dependent on the disturbing effect of the sun's heat upon the regions of cloud, and also through the effect of the daily axial rotation of the earth. In support of this opinion Fig. 29 is presented, which shows the mean hourly velocity of low-area storms, generally those to the eastward of the 100th meridian, and the mean velocity of the air as determined from observations from 1881–87 on the summit of Mount Washington (6279 feet). This figure shows the most striking accord between these two phenomena. The observations on Mount Washington cannot be considered as absolutely correct, owing to the great difficulty of securing



Mean hourly velocity of Low Area Storms, and Upper Air Currents on Mount Washington.

FIG. 29.

continuous registration of the wind. During very many days of the year the accumulations of frost upon the anemometer are such as to quite materially reduce the velocity, which probably for some months should be one to two miles greater than is shown in this diagram. On the other hand, there appears to be little doubt but that the anemometer records a velocity too great by eight to twelve per cent at velocities between twenty-five and forty miles, so that the reduction of the anemometer observations to a standard would undoubtedly involve a greater correction than the loss through frost-work upon the anemometer. In such a case there is good reason for believing that, after proper corrections, the two lines would be more closely in accord than is shown in the present diagram.

An examination of the records of the velocity of the wind on Mount Washington for eighty months shows that in departures from the normal the average velocity of the wind, in sixty per centum of the months, differs five miles or less from the departures in the velocity of storm areas, and that in fourteen per centum more of the cases the differences of departure are between five and one-tenth miles and seven miles. Further, it appears that in fifty per centum of the cases the maxima and minima monthly velocities of storms and upper air currents are in accord, representing in identical months the extremes of these phases.

It not infrequently occurs that low-area storms pursue decidedly abnormal paths—*i.e.*, toward a point in the western quadrants—from south to northwest. These abnormal movements result most frequently when in the abnormal direction occurs predominating rainfall, either locally heavy or widely distributed, or when the adjacent high areas assume such relative positions that their outflowing currents facilitate the inauguration of a distinct system of cyclonic winds, as a new storm-centre.

In many cases this abnormal westerly movement is rather apparent than real, since the storm-centre is either retarded and coalesces with another, or its energy is being gradually dissipated. In either case it may be held that the original storm vortex is destroyed, and that the mere fact of the lowest pressure being found to the westward after such changes does not indicate that the original vortex has moved in that direction. Doubtless, too, at times the easterly movements of upper air currents are interrupted, from general and widespread disturbances of the atmosphere quite beyond our ken, and since the strata into which the indraughted air passes has an abnormal movement, the surface conditions undergo a corresponding displacement.

The violent low-area storms of the West Indies, Southern Indian Ocean, Bay of Bengal, and China Sea have peculiar characteristics which place them in a special class. Known in the United States as cyclones or hurricanes of the West Indies, they are called cyclones in India, hurricanes at Mauritius, and typhoons in the China Sea. They are always accompanied by heavy and frequently by torrential rain, follow parabolic paths (first to the westward, and then to the north, and finally—unless, passing into the interior of a country, the storm is broken up—to the northeast), have limited nearly circular areas, sudden, sharp falls of the barometer, steep gradients, violent winds, and a slow movement of translation. About ninety per centum of the cyclones in the West Indies occur in August, September, or October. In Asiatic waters these storms prevail both during the above-named months and in April, May, or June, being most frequent, as has been set forth on page 164, at the "bursting of the monsoon." The storm tendency is, however, considerably greater in India during the autumnal months than in the spring, except on the Bombay coast, when spring cyclones are three times as frequent as those of autumn.

The cyclone, if of smaller extent and more regular formation, is more dangerous than ordinary storms, owing to the extreme violence and sudden shifting of its winds. The side of the path toward which the curvature tends—the right-hand half for West India storms—is known as the *dangerous* quadrants. This is owing to the continual tendency of the winds of these quadrants to carry vessels near to or in front of the centre—the most dangerous position—so that a vessel cannot run before the wind, but must heave-to. The other quadrants are called *avoidable*, since in them a vessel can be put before the wind, and thus avoid the central vortex.

As has been long since pointed out, the cold winds following in the wake of low pressure do not, near the surface of the earth, blow with a velocity equal to the progress of the storm-centre itself, and some comment has been made as to this being an inexplicable phenomenon. It, however, appears very simple of explanation, for it is well known that upper air currents move with a far greater velocity than do the surface winds, and there is no doubt but that these upper currents move with as great, or possibly even greater, velocity than does the storm-centre itself. The cold, dry air which flows in behind the storm at the surface of the earth is greatly retarded by the friction, and also by the fact that, when retardation through friction is once inaugurated, the current must be a slightly descending one, and the greater the retardation the sharper will be the curve of the descending air currents. Whenever the character of the surface (as, for instance, that of the great lakes or the ocean) is such as to reduce the friction to the minimum, these following winds will blow with much greater velocity near the earth's surface than they do over the broken lands. Instances verifying this opinion are apparent on any weather map of the United States where the low area has been sharply followed by the descending high area. It is probable that the abnormally high winds of Sandusky, O., Cape Hatteras, N. C., and other exposed points along the lakes and seaboard can be explained by the sudden diminution in the amount of friction experienced by the surface winds.

To summarize, low-area storms have a wind circulation inward and upward, are elliptical in form, in the United States, generally, have their major axis from W. S. W. to E. N. E., have a mean velocity varying from 600 to 900 miles each day,* move in the same general direction, probably, as the upper air currents, usually toward a point varying a little from due east, are characterized in their eastern quadrants by cloudy weather, southerly and easterly winds, precipitation, temperature oppressive in summer and abnormally high in winter, falling barometer, increasing humidity ; and followed by clearing weather, rising barometer, decreasing humidity, and falling temperature in the western quadrants. These latter changes are more decided in the United States than in Europe, since in this country the air drawn in behind the depression is a cold, dry current from the comparatively high press-

* The cyclones of the West Indies travel with only about one half of this velocity. It is to be noted that the progressive movement of storms is less rapid over ocean than across land.

ure of sub-arctic America, while Europe receives somewhat humid and cool winds, whose force fails to attain the maximum, on account of the permanent low pressures to the northwest in the vicinity of Iceland. When the pressure to the northwest of Great Britain is abnormally high, from April to June, the conditions in the wake of storms are almost as persistent and marked as in the United States, the northwest winds being stronger, colder, and dryer than at other seasons.

CHAPTER XIV.

CYCLONES AND HURRICANES.

THE difference between an ordinary storm and a cyclone consists largely in the path of the storm's movement, although some other characteristics distinguish it from an ordinary low-area storm, as has been set forth in a preceding chapter.

The cylcone of August 16th to 22d, 1888, has been selected as a storm representative of both the hurricanes from the West Indies and an ordinary low-area storm of the United States. It will be noticed from the track on Fig. 30 that this storm travelled in the usual parabolic path, that its change of curvature from the northwest to the northeast took place in about latitude 30° N., that its velocity from the Gulf of Mexico was considerably lower than over the land, and that this velocity, which was slowest near the apex of the parabola, increased to a marked extent after the change in its direction of motion to the northeast had taken place.

The weather conditions at 8 A.M., August 21st, are shown in Fig. 30 by conventional signs. Clear weather prevails over the unshaded part of the map and rainy weather over the deeply shaded part, while the intermediate tint represents the districts covered with clouds. The small figures near each station show the amount of rain which has fallen in twelve hours previous to the time of the map. The arrows fly with the wind, and by the number of *flèches*, or barbs, indicate its strength. Six *flèches* would represent the strongest winds known, and one denotes light airs. The dotted

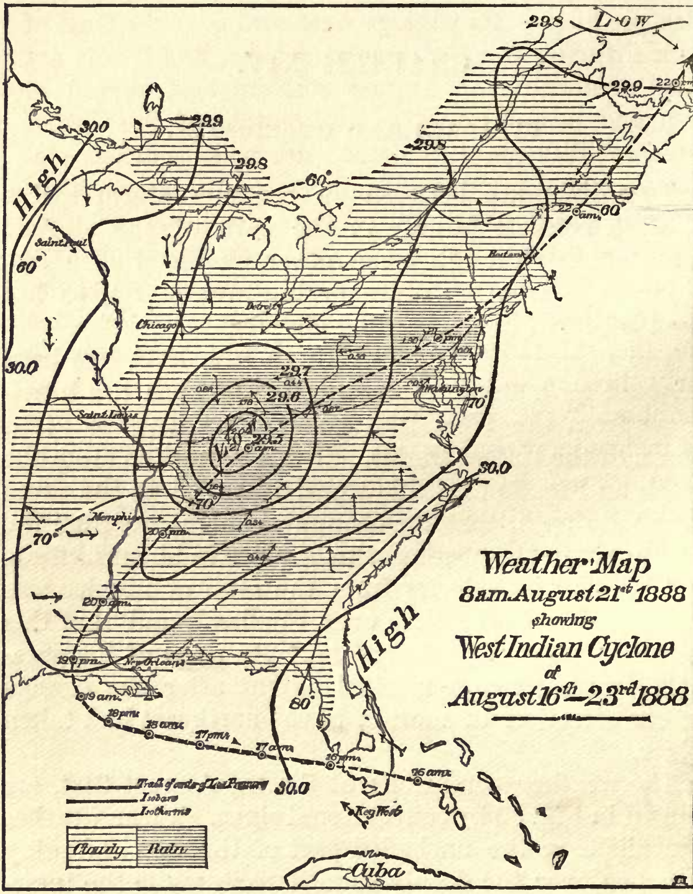


FIG. 30.

path shows the entire track of the centre of the cyclone, and the circles designate its position at 8 A.M. and 8 P.M., respectively, on the dates placed over them.

The storm was first indicated, August 16th, 1888, by very heavy precipitation, 2.20 inches in twelve hours, at Point Jupiter, Fla., with an easterly wind of sixty miles per hour. Its passage westward over the Gulf of Mexico during the 17th was very slow, and it was not until the morning of August 20th that it curved to north and passed into the land regions of the United States, in Western Louisiana. Its most marked violence over land regions did not occur until the night of the 19th–20th, when its passage northeast to Tennessee was marked by violent southerly winds of fifty-five miles at Mobile, La., and sixty miles at Pensacola, Fla., together with heavy precipitation. At the same time, the rainfall at Vicksburg, Miss., amounted to nearly three inches in twenty-four hours, while that at Memphis, Tenn., near the path of the cyclone, was 3.74 inches in twelve hours. By 8 A.M. of August 21st it had moved into Central Kentucky, where the barometer stood, at Louisville, 29.46 inches, with about two inches of rainfall over all of Kentucky and Central Tennessee.

The peculiar characteristics of a low-area storm were everywhere evident, and in observing this storm, as shown in Fig. 30, the pertinence of Buys Ballot's law of winds is at once evident. This law is that in the Northern Hemisphere, if one stands with back to the wind, the lowest barometric pressure will be invariably to the *left* hand. In the Southern Hemisphere the lowest pressure is always to the *right*. It will be observed that the eighteen circumjacent stations in Kentucky, Tennessee, and from Illinois eastward to Indiana have winds which are entirely in accord with this law, and that these winds are blowing inward toward the centre, crossing the isobars at angles varying from fifty to eighty degrees. This inclination is somewhat less than in the case of the Indian cyclones, where Blanford says that in the northeast and northwest quadrants one must face the wind exactly and the direction of the storm centre will be eleven points (about one hundred and twenty-five degrees azimuth) to the right. This rule, he adds, is not so *exactly* applicable in the southern quadrants.

In the easterly quadrants are seen cloudy weather and rain, with easterly winds and high temperature, and in the western quadrants winds from north to west, lower temperature, and clearing weather. At this period of the storm's history it might be inferred that its subsequent direction would be to the northeast, so as to cross Lake Ontario and pass down the valley of the St. Lawrence—a course followed by so many low-area storms of the United States. It is possible, as has been suggested by Lieutenant Dunwoody, that the later slightly abnormal movement of the storm to the east-northeast, instead of to the northeast, might have been predicated from the peculiar path before the recurvature; since in many cases it happens that the angle of inclination toward the northwest in the west path before such recurvature is substantially the same as that followed to the northeast after recurvating. However this may be, there were good reasons for predicting that the storm would pass to the east-northeast, the most obvious of which has been dwelt upon in the preceding chapter—that is, heavy rainfall in front of the storm. It will be noticed that in the previous twelve hours to 8 A.M. of August 20th—the time of the storm shown in Fig. 30—no rain had fallen at any station on Lake Erie or Lake Ontario, but that the heavy rainfall of an inch and a half had occurred at Harrisburg, Pa., in the twelve hours, while more or less precipitation had occurred at other places in Pennsylvania, Maryland, and Virginia. It was doubtless the influence of this precipitation and of the cloud formation accompanying it which determined the more easterly path of the cyclone.

Nearly three inches of rain fell within the twelve hours following over Southern Pennsylvania, New Jersey, and the vicinity of New York, in the direct path over which the cyclone later passed, and its subsequent passage to the east-northeast through Connecticut was marked by rainfalls between three and four inches in twelve hours, in *advance of the centre.*

The passage of this storm resulted, as do all the hurricanes of the West Indies which pass over any land region, in immense damage to crops, buildings, bridges, and everything which could be injured by excessive rains, severe local floods, or violent winds. In Louisiana alone the damage was estimated at about one half million dollars, and it is probable that the damage for the whole country could be hardly less than a million dollars.

This storm, however, was not one of the most violent of those from the Caribbean Sea, of which the following are mentioned as the most remarkable and destructive of late years.

The hurricane which devastated Guadaloupe, September 6th, 1865, is notable not only for its destruction of property and life on that island, but also owing to the very remarkable decrease of pressure, 1.693 inches in seventy minutes—from 29.646 at 6.30 A.M. to 27.953 at 7.40 A.M.—which occurred during its passage.

The hurricane of August 14th–27th, 1873, known as the Nova Scotia cyclone, was the most destructive storm which has ever visited the Atlantic coast. It recurved between the island of Bermuda and Cape Hatteras, N. C., and its centre at no time touched the coast line. Its ravages were such that the storm has well been termed terrible. Twelve hundred and twenty-three vessels were known to have been destroyed by it, and 223 human lives were definitely reported as lost.* It was estimated that, including crews of missing vessels and lives lost on land, at least six hundred persons perished from this hurricane.

The storm seriously crippled the fishing industries of both Canada and the United States, and besides bringing sorrow and death to hundreds of homes, entailed a pecuniary loss estimated at over three and one half millions of dollars.

A cyclone secondary to this in violence, but also marked by a fearful loss of human life, is that of September 15th, 1875, which, recurving at Indianola, Tex., and nearly destroying that town, moved northeastward across the United States, and left the coast between capes Henry and May. There were serious marine disasters on the New Jersey coast, but these sank into insignificance compared with the fate of Indianola. Hurricane winds of eighty-eight miles per hour were recorded at that place, which, with a general inundation from the sea, proved fatally disastrous. One hundred and seventy-six lives were lost and three fourths of the town was swept away, entailing a loss of over a million dollars' worth of property.

In September, 1877, a hurricane on the 21st passed near to Barbadoes and on the 23d swept over Buen Ayre and Curaçoa. On the latter island shipping was much damaged, solid buildings in the city of Curaçoa

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* A full account of this storm, prepared by Professor C. Abbe, is to be found in the report of the Chief Signal Officer, 1873.

swept away, many lives lost, and a damage over two millions of dollars done to property. After recurving, it moved across Florida near St. Mark's, and passing over Chesapeake Bay left the Atlantic coast near Cape Cod. Its passage through the Atlantic States, marked by violent winds and excessive rains, did great damage to cotton and rice crops, bridges, railroads, etc., and shipwrecked several steamers and other vessels.

Hurricane, October 21st–24th, 1878. It first damaged buildings and sank vessels at Havana. It entered the United States near Wilmington, N. C., and moving due north, passed over Washington and Eastern Pennsylvania, after which it curved eastward, and, crossing New England, left the coast near Portland, Me. In Philadelphia over seven hundred substantial buildings were totally destroyed or seriously damaged, bridges injured, twenty-two vessels sunk, several persons injured, and eight perished, entailing a loss variously estimated from one to two millions of dollars. Other loss of life and great damage by freshets and winds occurred elsewhere in Pennsylvania. A large number of steamers, ships, and coasting vessels were dismantled, wrecked, or sunk along the New Jersey, Virginia, and North Carolina coasts, entailing loss of life and enormous pecuniary damage. The wind reached seventy-two miles per hour at Philadelphia, and from eighty to eighty-eight miles along the coast.

Hurricane, August 16th–20th, 1879. Entered the United States at Cape Lookout, N. C., and skirted the Atlantic coast, thence northeastward to Eastport, Me. An enormous amount of damage resulted from this storm. Not only was the injury to inland property very excessive, but the damage to maritime interests may be estimated from the fact that over one hundred large vessels were shipwrecked, dismantled, or disabled, and two hundred yachts or smaller vessels injured. The wind reached a measured velocity of 138 miles per hour at Cape Lookout, where the anemometer was carried away. The barometer fluctuated with extraordinary rapidity, there being off the New Jersey coast a fall of 0.85 inch in five and one half hours, followed by a rise of 0.93 in six and one half hours.

Jamaica hurricane, August 17th, 18th, 1880. Devastated nearly all Jamaica, at least twelve lives being lost and hundreds of buildings destroyed.

August 23d–28th, 1881. Entered the United States near Savannah and followed a very unusual course to the northwestward to Minnesota. The loss of life and damage to property in Charleston, S. C., Tybee Island, and along the adjacent coast were very great. About four hundred persons lost their lives, and hundreds of houses were totally destroyed. The loss of property is estimated at over one and one half millions of dollars. A similar storm passed over Charleston August 23d, 24th, 1885, where damage to the extent of nearly two millions of dollars was done, and twenty-one lives were lost.

At Manzanilla, October 27th, 1881, a hurricane wrecked all vessels but one, and destroyed nearly every house, entailing a loss of $500,000.

A hurricane, October 8th–14th, 1882, crossed Cuba, causing great loss of life and enormous destruction to property. Thousands of houses were completely demolished and others seriously damaged. About forty persons were killed and thousands of cattle drowned. Its passage along the Atlantic coast was marked by violent gales and great loss of shipping, but urgent and timely storm warnings detained most vessels in port until the hurricane passed. Fifteen steamers and over two hundred sailing vessels, covering property estimated to be from eight to ten millions of dollars in value, were detained at New York by timely notice of the violent storm. On the Labrador coast over seventy vessels were lost, and probably 100 men perished.

August 19th, 20th, 1886, a cyclone completely destroyed Indianola, Tex., which, as before stated, was nearly swept away in September, 1875. Not a house was left standing, and over twenty lives were lost. Galveston, Tex., also suffered great damage.

It must not be supposed that even the worst of the cyclones of North America stand unequalled in violence, destruction, and death-list. The violent cyclones of the Indian Ocean and the China Sea have been at times so destructive, not of property alone, but of human lives, that the mind of any reflecting man is appalled at the record of misery and death wrought by these terrible outbursts of nature's forces.

The great difference between the pressure at the storm centre and its rear sometimes causes a storm wave to follow in the path of the cyclone, thus overwhelming such low-lying level lands as are in its course. In such cases, if the land is inhabited, the loss of life is occasionally enormous.

The Calcutta cyclone of October 5th, 1864, followed by a storm wave of sixteen feet over the level delta of the Ganges, caused the death of 45,000 persons.

The Backergunge cyclone of October 31st, 1876, was accompanied by an unparalleled storm wave, which covered the eastern edge of the delta of the Ganges with water from ten to nearly fifty feet deep. According to the lowest estimate, over one hundred thousand persons perished from this wave.

CHAPTER XV.

AREAS OF HIGH PRESSURE.

As may be inferred in the treatment of low areas, they are nearly always of sufficient intensity to merit the name of storms, but such term can be applied less frequently to the other systems of pressure, known as high areas, in which the barometric pressures are defined by isobars successively higher toward the centre.

The high areas are quite frequently called anti-cyclones, since the general direction of the winds connected with high-area storms is almost diametrically opposite to that of the low-area winds. Buys Ballot's law applies to anti-cyclones as well as to cyclones—that is, when one's back is to the wind the barometer is *lowest* in the Northern Hemisphere to the *left* hand and *highest* to the *right* hand. It thus follows that in the cyclone, as has been set forth, the winds blow inward, in a direction contrary to the motion of the hands of a watch in the Northern Hemisphere, and the winds of a high area, or anti-cylcone, blow outward, in a direction agreeing with the motion of the hands of a watch. The angle at which the winds blow outward in anti-cyclones is somewhat slighter than the inclination of winds inward toward the centre of a low area.

The isobars enclosing high areas are somewhat more regular than those of low areas, but rarely assume either a circular or pronounced elliptical form. Professor Russell has invited the author's attention to the recurrence of anti-cyclones with triangular-shaped isobars. Many such cases appear on the United States weather maps, of which a typical one is that of January 13th, 1885.

In the United States anti-cyclones are about forty per centum less frequent than low-area storms.

The number of high areas increases slowly from five in June to eight in January, February, and March, and then decreases regularly to June again. It is more than probable that the velocity of the movement changes correspondingly, as in the case of low areas, with the varying frequency—that is, the average velocity is lower in the summer months, when such storms are infrequent, and is at its maximum during the winter months, when the greatest number of cyclones or anti-cyclonic areas occur. Owing to the less relative importance of anti-cyclones, their progressive movement has not been determined as frequently or satisfactorily as the movement of cyclones. In all cases where such velocity has been determined, it appears that high areas do not move with the same average velocity as do the low areas, the difference amounting to ten or fifteen per centum.

Probably not more than one third of the entire anti-cyclonic areas can be classed as storms, if that term is closely restricted to atmospheric disturbances of such extent as to materially modify the course and at the same time augment the velocity of the surface winds. Indeed, most of the anti-cyclones in summer are attended by light or fresh winds of sufficiently low temperature to agreeably modify the excessive summer heats of the United States. In winter the advance of these high areas, though always attended by a decided fall in temperature, is for the most part characterized by calms near the centre and light or fresh winds on the outskirts of the area, the winds not rising to a sufficient strength to be either important or dangerous.

Although the advancing edge of an anti-cyclone, especially when following closely in the wake of a passing low area, is often accompanied by high winds and precipitation, in the form of snow or rain, yet such is not the predominating characteristic of these areas. As a general rule, the anti-cyclone is marked by clear skies, abnormally low temperature, and calms or light winds. Near the centre of the area especially there are neither surface winds nor clouded skies. This clear, calm condition of the atmosphere at the surface of the earth permits rapid nocturnal radiation, while at the same time the air strata near the earth gain no heat by convection.

This condition of affairs tends to lower the temperature of the air at the centre of an anti-cyclone, if, indeed, this process of nocturnal radiation through a very dry atmosphere is not the important factor in inducing and continuing the abnormally low temperature. In connection with this point, it is interesting to note that far the greater part of the anti-cyclones of the United States come from Manitoba or Saskatchewan, yet the lowest temperature noted in such areas obtains not in the northern parts of these districts, but very near the 49th parallel, the boundary-line between the United States and British America. It seems probable that in its passage southward the air becomes gradually colder, owing to the favorable conditions of the high treeless plateaus for nocturnal radiation, but finally a point is necessarily reached in the southward course where the days are longer, and the heat received from the sun must more than counterbalance that lost by nocturnal radiation. The absence, too, of aqueous vapor tends to increase the density of the air, and possibly these two conditions, creating dryness and very low temperatures, are sufficient to cause the increased density of the lower strata of the air to such an extent as to form an anti-cyclone.

It is believed that far the larger number of anti-cyclones which pass eastward over the United States are of limited depth, as shown by conditions on the summit of Mount Washington (6279 feet). It has been noticed frequently by the author that a large number of anti-cyclonic areas depend for direction and motion upon phenomena occurring in strata of air of very moderate thickness, since the Alleghanies, the Blue Ridge and at times even the low mountains in Arkansas are sufficient to break up, divert, or materially modify the course and action of such areas.

In connection with anti-cyclones there prevail, however, from time to time, especially in the winter months, severe storms of wind, either with or without snow. When accompanied by snow they are popularly known in the northwestern part of the United States as "blizzards." These will be treated of in a subsequent chapter, in connection with the sudden, severe, and widely-extended changes of temperature known as cold waves.

Apart from these storms, which occur through the rapid advance of an anti-cyclone in the wake of a cyclone, may be mentioned other storms which result from the natural operations of the anti-cyclone itself, independent of any well-defined adjacent cyclone.

It was remarked first by Franklin, I believe, that the phenomena in the United States known as northeast storms, while attended by northeast winds, really came from the southwest, and that such storms prevail first in Pennsylvania, later in Connecticut, and still later in Maine. While this is true as a general rule, yet there are marked exceptions. Franklin's observations and theory were sound as far as they went, but it has been shown by the experience of so remarkable and skilled a meteorologist as Dove that special meteorological phenomena pertain to limited sections of the earth's surface, and that any deduction from local atmospheric changes cannot be rigidly applied in a general manner. Dove's opinion on the march of weather phenomena in connection with the passage of low-area storms over Europe was based on observations covering France and Germany—countries which, as a rule, lie to the southward of the storm tracks—and his statement left unconsidered the march of such phenomena on the north side of the storm tracks, such as obtains so frequently in Scotland and Iceland.

In like manner, the northeast storms which prevail in connection with anti-cyclones are infrequent, and so have not received the attention they deserve. Their very infrequency and suddenness make them, however, dangerous, since they come, as it were, as a thunderbolt from a clear sky, the storm frequently beginning first along the Southern New England coast as a northerly one and extending southward to the New Jersey and North Carolina coasts, in which latter places they change to northeasterly and blow with exceeding violence.

A typical case of such northeasterly gales is that in connection with the anti-cyclone of October 13th–16th, 1884. Its centre was over North Minnesota, October 13th, from which section it moved eastward across the great lakes, and was to the northward of Lakes Erie and Ontario on October 15th. In connection with this area, the winds during the 14th blew from the north and northwest in New England, while on the New Jersey and North Carolina coasts they were from the northeast, fortunately with a clear sky. For over twenty-four hours the wind along the New Jersey coast blew with a velocity ranging from twenty-five to the unusual velocity of fifty-two miles per hour, and along the North Carolina coast from twenty-five to forty-seven miles per hour. Along all these coasts north-easterly gales were experienced, causing more or less damage to shipping. There was no connection with any other adjacent storm centre, and the winds were purely anti-cyclonic. It may further be advanced that these winds were higher than the barometric gradient appeared to justify, and it is probable that their force largely depended on a temperature gradient.

Chart showing Anti-Cyclone at 8 a.m. Jan., 12, 1886.

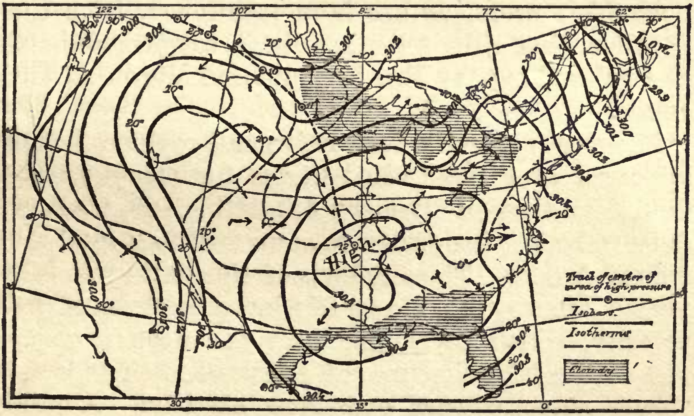


FIG. 31.

The conditions represented on Fig. 31 are characteristic of anti-cyclonic storms. The centre in Southern Missouri and Northern Arkansas is marked by calms or light winds. The weather over the entire country is clear, there being no clouds except at a few coast and lake stations, and precipitation in the previous eight hours has occurred only on the Texas coast, in the form of light snow.

This anti-cyclone followed the path peculiar to many —that is, from Dakota southward to the vicinity of the Gulf coast, whence high areas drift eastward with the general atmospheric circulation. During the prevalence of such areas the cold period is prolonged, rarely being less than five, and frequently as much as seven days in duration.

Another path much frequented by anti-cyclones is from Manitoba eastward to the Gulf of St. Lawrence. In such cases the northern part of the country only is affected by the fall of temperature, which is sharp and of brief duration, rarely exceeding three days. Such high areas, as has been mentioned, from their peculiar wind circulation are liable to produce northeast gales along the New England and Middle Atlantic coasts.

The most generally destructive anti-cyclone that has appeared over the United States for many years is doubtless that of January 5th–14th, 1886, when the damage by low temperatures amounted to several millions of dollars. The outskirts of this anti-cyclone appeared January 6th, in rear of a low-area storm of great severity, which developing over the western part of the Gulf of Mexico, moved eastward to Georgia, and thence northeastward over New England. A steady outflow of cold air from British America continued for several days, during which time it appears probable that the centre of the high area moved in a direction a little east of south from the Pease River country to Eastern Dakota, where it was central on the 11th. At this time the temperature was more than thirty degrees below zero in British America, while zero temperatures covered the entire Missouri Valley and the Mississippi Valley southward nearly to Vicksburg. The progress in the next twenty-four hours was rapid, and on the morning of January 12th its centre was in Southeastern Missouri. From Missouri the area drifted eastward, and slowly passed off the Atlantic coast on the 14th.

The atmospheric conditions at 7 A.M of the 12th are shown on Fig. 31, on which chart is shown the track of the anti-cyclone from British America to the Atlantic seaboard. At that time the entire country to the eastward of the Rocky Mountains was affected by temperatures ranging from thirty degrees below zero over Canada to thirty degrees above zero at Brownsville, Tex. There was no portion of Florida from which reports were received but what experienced freezing temperatures and hard frosts, and only the extreme southeastern part of the State escaped injury. At Key West the temperature fell to forty-two degrees, the lowest ever recorded.

Galveston Bay froze over on the 9th, and snow fell through all of Southern Texas, from San Antonio southward to Brownsville, it being the first general snow in that region since 1866. At Pensacola, Fla., fresh-water ice formed to the thickness of three inches, and sea water froze along the edge of the bay. In Florida, at Manatee, Live Oak, Lake City, Cedar Keys, and Tampa, ice of considerable thickness formed. In Florida alone the damage to fruit and to other interests was estimated at over two millions of dollars.

The anti-cyclone of January, 1886, was the most noteworthy one for many years, as it induced in the Gulf States the lowest temperatures ever recorded, although a similar storm of about the same severity occurred in 1835.

A storm of a similar character occurred December 27th–31st, 1880, when the high-area central over Manitoba, on the morning of the 27th, moved due southward, and reached Central Texas on the morning of the 30th, whence it gradually moved eastward and dissipated. This anti-cyclone also followed low-area storms which passed from Texas to Georgia. This high area was nearly as severe as the one of January, 1886, as far as the Gulf States were concerned, and during it the lowest temperature for fifty years also occurred in many parts of Pennsylvania, Maryland, Virginia, and North Carolina.

During the anti-cyclone of December, 1880, the temperature fell at Fort Benton to fifty-nine degrees below zero, and on the morning of December 30th, 31st, freezing temperatures prevailed over the entire United States, except in the Pacific coast region, the southern half of Florida, and the extreme southwestern portion of Arizona.

As forming special and important classes of anticylones, cold waves and blizzards are considered sufficiently national and American to warrant their separate description in some detail.

CHAPTER XVI.

COLD WAVES AND BLIZZARDS.

THE term "cold wave" is a technical one devised by the United States Signal Service, not to represent the intensity of the cold, except within certain limits, but more especially to show very decided falls in temperature within a limited time. The cold wave of the Signal Service indicates (1) that the minimum temperature will sink to forty-five degrees Fahrenheit or below, and (2) that a fall of fifteen degrees or more will take place from any given hour of one day (as 8 A.M. or P.M.) until the same hour of the next day. As has been shown in treating of ranges, it is no unusual thing at elevated stations in Arizona for the temperature to fall fifty degrees from the maximum of one afternoon to the minimum of the next morning, a period of twelve or fourteen hours; but in most of these cases the fall from the maximum or minimum of one day to the maximum or minimum of the succeeding day would probably not exceed eight or ten degrees.

The modification of the winter temperatures of the United States, through its topographical features, was incidentally referred to on page 106, and may now be slightly enlarged on with reference to the distribution of cold waves.

The movement of any low-area storm has, as a necessary accompaniment, the indraughting of air in its wake, to replace that drawn spirally inward and upward at the moving storm-centre.

As is shown on Charts XX. and XXI., the low-area storms of the United States most frequently develop on the slopes to the eastward of the summit of the Rocky Mountains, whence they move to the Atlantic. If the country over which the storm-centre passes was a level plateau, or was devoid of marked breaks, in the shape of deep valleys and high mountain ranges, the quarter from which this air would flow in would depend on the direction in which the storm-centre was moving, modified, of course, by the law of cyclonic winds and by deflection due to the daily axial rotation of the earth. But there are very marked topographical features in the United States, which result in causing to advance from British America the greater part of the winds following in the wake of cyclonic storms. The Rocky Mountain range, averaging about nine thousand feet in elevation, is as high or higher than the upper strata of most low-area storms, and so the air current cannot be drawn from the westward. Again, the broad, vast valley drained by the Mississippi descends with a gradual and substantially unbroken slope from British America to the Gulf of Mexico, so that any air flowing northward must be considerably retarded in its movement by the great friction arising from moving over continually ascending ground. On the other hand, the air from British America passes off gradually descending surfaces, and this movement is further facilitated by the air being dry and cold, and hence dense, which naturally underruns with readiness the lighter, warmer air of the retreating low area.

It is thus evident why anti-cyclonic areas, especially such as cause severe cold waves, have a marked tendency to move southward, and even such cold waves as move east, with their centres in high latitudes, always affect the trans-Mississippi region to points much farther south than occurs in the eastern part of the country. The Rocky Mountain range is also higher than the top of most of the air strata which form cold waves, and thus the outskirts of these waves do not overflow into the tramontane regions. Such waves as prevail westward of the Rocky Mountain summit have their origin in localities to the westward or northwestward, and are drawn southward by the passage of low areas which also originate in the Pacific coast region.

The effect of even low mountain ranges in protecting a section from cold waves, as occurs in regard to the greater part of Arkansas and Northern Louisiana, is very noticeable. If there existed a transverse mountain range extending from the Rocky Mountains to the Mississippi River, Texas and other regions to the southward would be fully protected. The Appalachian range shelters to a great extent Virginia, the Carolinas, and Georgia, which are often entirely spared the severe cold waves experienced in the Ohio Valley and Tennessee.

A cold wave results from the movement of a strong anti-cyclonic area across the United States, and, as has been pointed out in a previous chapter, these areas have three different paths : one from west to east across the great lakes to New England ; second, a due southerly translation from Manitoba to Texas, whence they drift easterly with the general atmospheric conditions ; and, third, a path intermediate between the two.

It is not to be inferred that every anti-cyclone causes a cold wave. The limitations of summer temperatures are such that even the northwest portions of the United States are rarely subject to these phenomena in that season. During July cold waves are unknown; and in June and August not more than five per centum of the high areas are marked by conditions where the abnormal fall of temperature exceeds fifteen degrees in twenty-four hours and at the same time falls below forty degrees Fahrenheit.

During the remaining months of the year the percentages of anti-cyclones causing cold waves rise steadily from twenty per centum in September to a maxi mum of ninety per centum in January, and then slowly decrease to about twenty per centum in May. During January, in the extreme northwestern part of the United States, it is reasonable to expect on an average one cold wave in every five days, while in February and March they recur about weekly.

The greater part of the anti-cyclones which cause cold waves—probably ninety per centum—are outpours of dry air, chilled to a very low temperature by radiation over the barren grounds of British America. Without doubt, the very low temperature to which the air falls is due to the barren, treeless character of that country, which is covered with scanty vegetation during summer and free from ice or snow during the winter, so that the radiation from the bare ground proceeds with great rapidity during the long winter nights in this sub-arctic region.

The cold wave occurs not with the centre of the anticyclone, but on its outskirts, far in advance of the centre, and the great and sudden falls of temperature obtain most frequently when the movement of a low area to the eastward has raised in its passage the temperature of the adjacent country to an abnormally high point.

The passage of cold waves eastward is coincident with the movement of high areas, as set forth in a preceding chapter, and the outskirts of these anti-cyclones travel on an average from Manitoba to Texas within forty-eight hours, and in about the same time to the St. Lawrence Valley or the Middle Atlantic coast.

Lieutenant T. M. Woodruff has pointed out that the most decided changes of temperature obtain from 3 P.M. (about the usual hour of maximum temperature) of one day until 3 P.M. of the day following.

As yet it has not been determined with absolute accuracy what conditions must obtain to induce the passage of cold waves (1) to the southward, (2) to the east, or (3) to an intermediate point in the southeast. The question doubtless depends upon the relative relation of the centre of the anti-cyclone to that of some cyclone far distant.

The author, from considerable personal observation, is inclined to the opinion, however, that the easterly or southerly movement of any anti-cyclonic area, sufficiently marked to cause a cold wave, depends very largely upon the general direction and average latitude of the path followed by the last cyclonic area that has passed across the United States. The very destructive anti-cyclones of December, 1880, and January, 1886, were preceded by cyclonic storms, which moved eastward from the western Gulf in paths of unusually low latitude. The slow process of development, and the equally slow movement of these low-area storms to the eastward, resulted in inducing northerly winds in the northwestern quadrant for a number of days, during which time enormous quantities of cold air must have been drawn from sub-arctic America. In consequence, the whole lower air strata from Dakota to Kansas were abnormally cold and dry, conditions which facilitated local radiation, and still further re-enforced the outflow of cold, dry air to replace the surface strata drawn southward. Similar conditions—that is, continued northerly winds—obtained in rear of a similar low-area storm in March, 1888, and resulted in the combined cold wave and blizzard which wrought so much devastation and injury to Southern New England and the vicinity of New York City.

On the other hand, it is noticed that many of the anti-cyclones—those which pass easterly across the great lakes—follow in the wake of low-area storms of easterly paths, from Minnesota to the St. Lawrence Valley, in a comparatively high latitude. During the cyclone's development and passage warm southerly and easterly winds have prevailed over the United States, which winds not only were warmer than the local air strata, but also brought with them vast quantities of aqueous vapor, which, being set free by condensation, likewise tended to raise the temperature of the adjacent general atmosphere.

The following are among the most remarkable cold waves that have occurred in late years, and may serve for comparison with future ones in the United States:

March 19th–22d, 1876; causing violent *northers* on the Texas coast, with winds ranging from fifty to sixty miles per hour, and destructive frosts through all the Gulf States. In the northern half of Florida many orange and fruit trees were destroyed, and all early vegetables.

January 1st–7th, 1879; during which the temperature fell to $-60°$ at Battlefield, N. W. T., to $-5°$ near Washington, 25° at Jacksonville, Fla., and 46° on the Bermudas.

January 30th–February 1st, 1879; accompanied by a severe snow-storm in Nebraska, through which thousands of cattle later died, owing to lack of forage.

February 9th–14th, 1881; affecting Southern California, Arizona, and Texas. Ice formed at Campo, Cal., Indianola and Eagle Pass, Tex., and Mobile, Ala. The passage of this high area caused severe blizzards in Dakota, Nebraska, and Kansas, stopping all travel, destroying many thousands of cattle, and causing great suffering among the people for want of food and fuel.

This cold wave was unprecedented as to duration, severity, and prolonged movement to the southward. It moved rapidly southward, apparently traversing the Cordilleras, through Mexico, as Guatemala, on February 10th, was visited by a frost which was claimed, at the time, to be the heaviest within the memory of man. Ice formed in many places, while coffee-trees were damaged and sugar-cane killed. In Guatemala the value of crops destroyed was estimated to be over one million dollars.

That this cold wave extended so far southward is doubtless due to the unusual circumstance that a low-area storm, whose centre could not be definitely located for lack of reports, evidently prevailed over Northern Mexico from January 6th–8th. It passed to the Gulf of Mexico the night of January 8th, 9th, 1881, and was doubtless followed by the wave described above.

March 2d–4th, 1881; the advance of this anti-cyclone following closely a low-area storm caused a severe blizzard in Illinois, Indiana, Iowa, Wisconsin, and Michigan. In many localities the storm was said to be the most severe for a quarter of a century. The snowfall was generally heavy, so that the violent winds drifted it in many places to great depths. For several days, in the greater part of the States named, the roads were completely blocked, communication impossible, and all business suspended. Over two hundred tons of mail matter accumulated at Chicago, as all railroad lines to the West were closed. This blizzard entailed an enormous amount of suffering to thousands from lack of food and fuel during the blockade. Similar gales, with like results, were experienced in these same States during the 19th, 20th, 29th, and 30th, thus making March, 1881, a memorable month for snow blockades.

January 11th–15th, 1882. The Pacific coast region is rarely affected by severe weather, with freezing temperatures and general snows, and this anti-cyclone was, perhaps, the most remarkable in that section in recent years. It followed a low-area storm which had developed in Arizona to the southwestward of the Rocky Mountains. On January 13th, 14th, the weather in Central and Southern California was the severest ever known; heavy snow followed by freezing temperatures. Ice formed almost to the seacoast on the Mexican border, and snow-flakes fell at San Diego. At Stockton ice formed an inch thick, and at Merced one half inch thick. At Fresno the temperature fell to 21°, and at Campo (2500 ft. elevation), on the Mexican border, the minimum was 6.5°. The unprecedented fall in snow, mentioned on page 160, and the unusually low temperatures did great injury to sub-tropical plants and caused the death of many sheep.

February 18th–20th, 1882; a cold wave, during which the temperature fell to 10° at Fort Gibson, a fall of fifty-five degrees in twenty-four hours, followed in Texas by a fall of thirty-five degrees in the same length of time. This was immediately followed by a secondary high area, which caused falls in twenty-four hours of thirty degrees in Texas on the 21st, and from New York to North Carolina a fall of twenty-five degrees on the 22d.

January 6th–12th, 1883; an anti-cyclone inducing severe *northers*, with velocities of nearly sixty miles of wind on the Texas coast and freezing temperatures to include the northern half of Florida.

January 16th–20th, 1883; during this cold wave the temperature fell to twenty degrees below zero from the eastern part of Washington Territory southeast to Colorado and Western Kansas, and zero temperatures occurred as far south as Northern Texas and the northern half of Arizona. This cold wave was marked by a severe norther at Key West, with thirty-three miles of wind per hour and a temperature of 55°. The entire eastern country had a temperature below freezing, except the South Atlantic and East Gulf coasts. This wave caused immense suffering to the people of the whole country, killed a large amount of stock, and with the preceding one made January, 1883, from the Mississippi Valley to the Rocky Mountains, from eight to twelve degrees colder than the mean.

January 1st–3d, 1884; this wave caused freezing temperatures from Texas eastward to Northwestern Florida. The mean minimum temperatures through Ohio were sixteen degrees below zero, in Pennsylvania among the lowest recorded zero temperatures over all of Tennessee, and freezing temperatures, which injured orange groves, occurred as far south as Manatee, Sanford, and Limona, Fla. The minimum temperatures over Montana, Dakota, Minnesota, the central valleys and Southern States were generally the lowest recorded in fourteen years.

January 3d, 1885; marked by a minimum temperature of −63.1°, the lowest ever recorded in the United States at Poplar River, Mont.; it caused falls of temperature during the twenty-four hours, ranging as great as thirty-seven degrees in the lower lake region, forty degrees in Tennessee, thirty degrees on the Atlantic coast, and twenty-six degrees in the Gulf States.

January, 1886, as described in the preceding chapter. (See Fig. 31.) Temperatures in Montana fell from forty to fifty degrees in advance of its centre, the most sudden changes being fifty-five degrees in twenty-four hours at Helena, and fifty degrees in eight hours at Fort Maginnis. This cold wave was marked in Texas by an unprecedented fall of temperature—fifty-four degrees in less than eighteen hours at Galveston, where the minimum was 11°. The temperature fell below zero at Atlanta, Ga., snow extended as far south as Fort Gatlin, Orange County, Fla.—the first time on record. In Georgia the Ogeechee Lake froze, for the first time as far as is known, and also the Oconee River. Ice formed to the thickness of three inches, and several persons froze to death at or near Charleston, S. C.

February 9th–11th, 1885; during which the temperature fell in twenty-four hours fifty-two degrees at Pittsburg (forty-two degrees in eight hours), from twenty-five to forty degrees in the West Gulf States, from fourteen to twenty-seven degrees in the Mississippi Valley, from twenty to forty degrees in the lake region, and between twenty and thirty degrees along the Atlantic coast from Florida to Maine. This cold wave caused the lowest temperatures known for February in many years in Ohio, Illinois, Wisconsin, and New York.

February 3d–5th, 1886; a very severe wave, during which the temperature was below freezing along the East Gulf coast and below zero from New England westward to Iowa. The minimum temperatures were generally the lowest ever observed in February in the Ohio Valley, Tennessee, and the Middle Atlantic States.

March 20th–24th, 1885; this cold wave is notable as producing unusually low temperatures at a late season of the year. It caused a fall in twenty-four hours of about twenty degrees through the Gulf and South Atlantic States. At Escanaba, Mich., a temperature of $-25°$ occurred on the 21st, one of the lowest temperatures ever recorded in March, and the lowest ever known at so late a date. The Delaware River froze over at this date at Easton, Pa., and the Lehigh at South Bethlehem, Pa., for the first time during the winter, and all canals in the State were closed. North and East rivers at New York City were filled with large quantities of ice, obstructing navigation for several days. New Haven Harbor, Conn., and the Potomac River at Washington both froze over. Freezing temperatures were experienced as far south as Pensacola, Fla., and great damage was done to early vegetation all through the Gulf and South Atlantic States.

February 11th–19th, 1887; *two anti-cylones.* Particularly felt in Missouri, Montana, Colorado, and Northern Texas, in all of which sections the temperature sank from forty to fifty degrees in eight hours, and from fifty-two to sixty degrees in twenty-four hours. At Lamar, Mo., the fall in nine hours was fifty-eight degrees, and in twenty-four hours sixty and three-tenth degrees—one of the largest ever recorded in the United States for that period. For nearly three weeks rail communication was blockaded in Southeastern Dakota and telegraphic and rail communication interfered with in Minnesota and Northern Michigan.

February 1st–3d, 1887; the advance of which was marked in Montana by falls of temperatures of from forty-five to fifty-five degrees in twenty-four hours, with drifting snow, causing in that Territory the loss of a large number of cattle from starvation, and delaying for many days all communication by stage and rail lines. In Dakota the winds were high, snow heavy, and the temperature extremely low, causing a large number of cattle to perish by exposure, or later by starvation, owing to the ground being covered with crusted snow.

March 3d–6th, 1887; this anti-cyclone was marked by freezing temperatures as far south as the 36th parallel, and zero temperatures from Dakota to Northern New England. In its passage across the last-named section the temperatures fell in New Hampshire and Maine with remarkable rapidity, the changes ranging from fifty to seventy degrees from the noon maxima of March 4th to the morning minima of the 5th. At Berlin Mills, N. H., the change in this time amounted to sixty-seven degrees, and at West Milan, N. H., was seventy-one degrees.

March 24th–30th, 1887; this cold wave was unusually severe, considering the lateness of the season, in Alabama, Georgia, North and South Carolina. Very severe frosts were experienced in the interior of all these States, where the early fruits and crops were damaged extensively.

BLIZZARDS.

Among one of the first to mention the *blizzard* was Henry Ellis, who made a voyage to Hudson Bay in the ship *California*, in the year 1746, and wintered near York Factory. He speaks of the northwest wind as being exceedingly trying, not only on account of the intense cold, but owing to the air being filled with fine, hard particles of snow, which made it almost unbearable. The first use of this term by the Signal Service was in one of its publications, *The Monthly Weather Review*, in December, 1876.

One of the most severe blizzards within the past quarter of a century was that which occurred in an unusually late period of the year in Dakota, from April 13th–16th, 1873, and in connection with or shortly after this storm the use of the word became tolerably frequent in the northwestern parts of the United States, to indicate such cold anti-cyclonic storms as are attended by drifting snow.

The Dakota blizzard of April, 1873, was of the most violent character, as is shown by the few recorded observations. The wind blew at Yankton, Dak., from the 13th to the 16th, inclusive, for a continuous period of nearly 100 hours, at an average velocity of thirty-nine miles per hour, and on April 15th the velocity for the entire twenty-four hours was over fifty-two miles per hour. This hurricane-like wind, unprecedented in the interior of the United States for continued violence, was accompanied by fine drifting snow, which was like sand, and so filled the air that one could not see a dozen yards. The Seventh Regiment of United States Cavalry was camped in Yankton at the time, and for more than forty-eight hours officers and men alike were obliged to seek shelter in the houses of the citizens. Business of all kinds was necessarily suspended, travel impossible, the suffering and damage prolonged and great. Large numbers of cattle were frozen to death. A considerable number of persons were badly frozen, but, fortunately, deaths were few, owing to the gradual increase in the violence of the storm and the fact that the Territory most affected was then thinly populated. It doubtless exceeded in violence and duration the more fatal blizzard of January, 1888, when scores of human beings perished in Dakota and Nebraska.

The most disastrous blizzard ever known in Montana, Dakota, Minnesota, Kansas, and Texas, occurred on January 11th, 1888. The change in the direction of the wind and the fall in the temperature was more sudden than usual. Although the greatest violence of the storm was of short duration, yet it was most destructive in its effects in Middle and Southern Dakota, owing to the fact that the change in wind, weather, and temperature came suddenly in the middle of a comparatively warm and pleasant day when many were away from shelter. The loss of life was probably nearly one hundred persons, although the exact figures are not known. High winds ranging from thirty to fifty miles per hour occurred, with falling and drifting snow, which, in addition to the great loss of human life, caused the destruction of herds of cattle and an enormous amount of suffering to entire communities. At Helena, Mont., the temperature changed with unprecedented rapidity, falling fifty degrees in four and one half hours and sixty-four degrees in less than eighteen hours. Communication by rail and otherwise was either seriously delayed or entirely suspended for several days in Northern Dakota and Minnesota. At Crete, Neb., the temperature fell eighteen degrees in three minutes, and snow drifted so violently as to render all travel dangerous. At Galveston, on the 15th, the temperature was below the freezing point, while the air was filled with fine drifting snow or freezing mist, which, owing to the influence of a wind of forty miles per hour, cut like drifting sand and coated everything with ice. At Rio Grande City and Brownsville, Tex., the wind was violent and the temperature fell nearly forty degrees in eight hours. The cold rain changed to snow and sleet, covering everything with ice, and causing great suffering.

A peculiar feature of this blizzard was its extension in the shape of a cold wave, without snow, however, into California. Slush ice was seen in the river at Sacramento for the first time since 1854, while ice formed in San Francisco to the thickness of half an inch. At and near Los Angeles ice and killing frost were general, and even at San Diego there was light frost and a thick film of ice in exposed places.

The most remarkable blizzard in the eastern part of the United States was that of March 11th–14th, 1888. The heavy snow and high winds attending it completely interrupted telegraphic and railway communication in New Jersey, Eastern Pennsylvania, and the southern half of New York and New England. Business was entirely suspended in these sections during the 12th and 13th. The advance of the anticyclone was marked by a sudden and rapid fall of temperature, heavy snow, and violent northwesterly winds, which not only made travel dangerous but almost impossible. For four days the average wind velocity throughout the sections named ranged from twenty to twenty-five miles per hour, and at times attained velocities varying from fifty to seventy miles. It has been shown by Prof. Upton that the snow was exceedingly heavy, averaging probably forty inches or more over Southeastern New York and Southern New England. The violent winds filled the air for one or two days with blinding snow, which drifted, under favorable circumstances, to a depth of ten or fifteen feet in New York, New Haven, and adjacent cities. It was five or six days before regular communication was re-established and ordinary business resumed. Many persons who faced the storm were badly frozen or prostrated by the low temperature, drifting snow, and high winds, and the loss of life from this cause, directly or indirectly, was considerable. New York, Philadelphia, and Boston were completely isolated, and the only advices possible for one or two days from the latter city were via London, England, by cable. At Delaware Breakwater only thirteen out of forty vessels escaped serious damage or destruction, and thirty or more lives were lost.

The maritime interests suffered from this blizzard to the extent of over one half a million dollars, while the losses by railroads and other business interests could not be accurately estimated, but must have aggregated several millions of dollars. The storm was quite as severe as any blizzard of the Northwest, and much farther reaching in working damage and destruction, owing to its occurrence in so densely populated a region. The highest recorded winds were as follows: Eastport, Me., seventy-two miles for a single hour, twenty-seven miles for ninety-six consecutive hours; Block Island, seventy miles and thirty-two miles; New York City, fifty miles and thirty-two miles; Philadelphia, sixty miles and twenty-six miles.

It must not be imagined that this storm is unequalled in the annals of this or other countries. England and France are thought by many to be entirely free from such variable weather conditions; but such is not the case. On January 18th, 19th, 1881, similar storm conditions obtained in England and France, with more disastrous results, and the description, except the larger number of deaths, would be strictly applicable to the American storm.

The gale was particularly severe on the east coast of England, accompanied by a heavy fall of snow through the 18th and till about noon of January 19th. The amount of snow over the whole southern portion of the country was very great. Snow-drifts of four to twelve feet were general throughout Southern England. The snow was so drifted by the wind that communication of every kind was entirely disorganized, and it was more than a week before the railway and postal arrangements throughout England and Wales were restored to their usual regularity. The interruption to business was further increased by the large number of telegraph wires broken by the gale. The snowfall in the Isle of Wight and in South Hampshire was altogether unprecedented in recent times. The loss of life in England and Wales, entirely due to the snow, was estimated at 100 persons, and the amount of distress occasioned by the stoppage of supplies of food and fuel was almost incalculable.

In France as far south as Paris the snowstorm was also very severe, and caused serious delays of mails and other business. Hundreds of market-wagons were abandoned in the heavy drifts, and many of the streets of Paris were completely blocked. At Lille, France, many houses were damaged and railroad travel completely suspended.

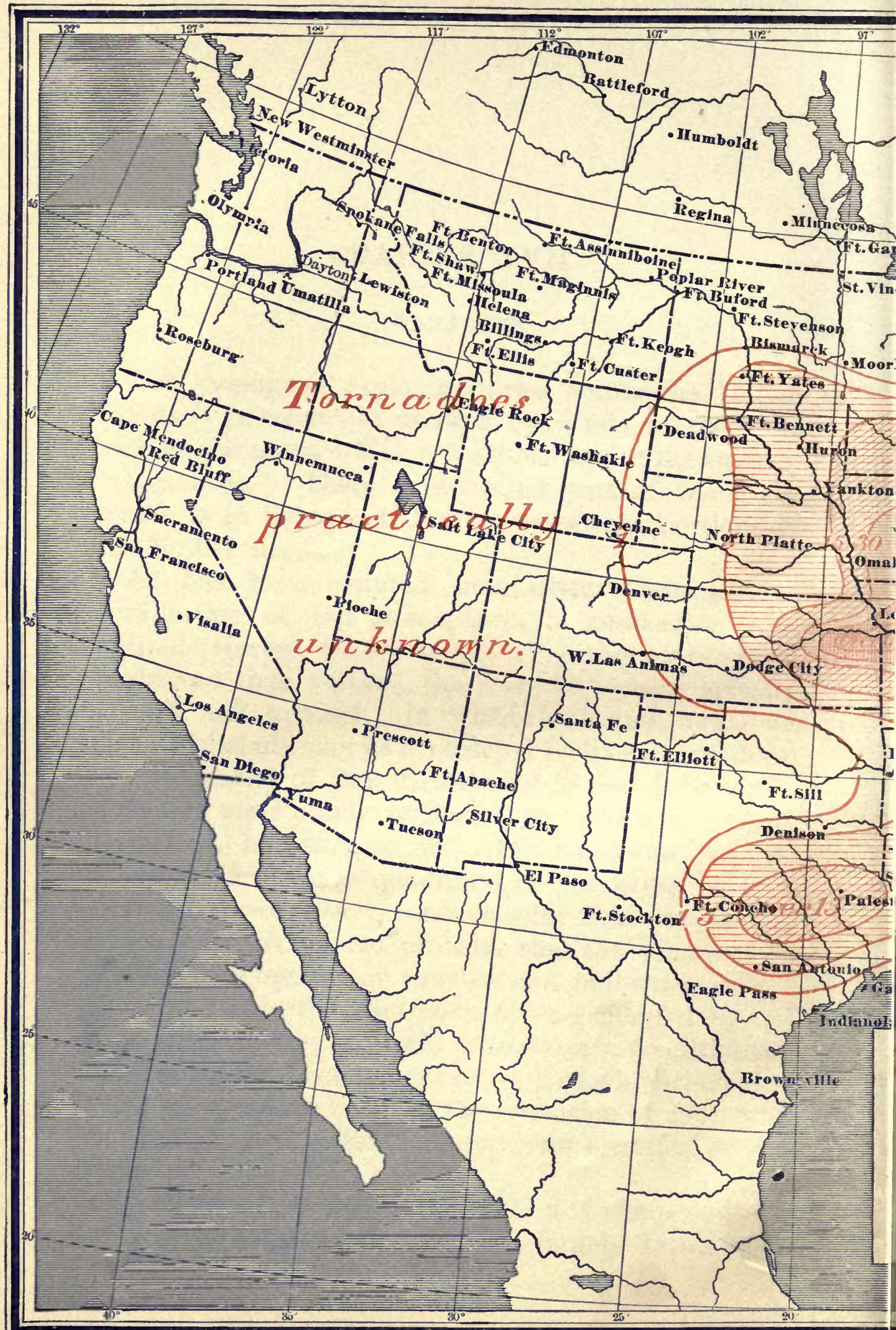
CHAPTER XVII.

TORNADOES.

THE passage of cyclonic storms across the United States is occasionally marked by winds of the most violent character, which are known under the name of "tornadoes." There is no other part of the globe which is as liable to tornadoes as certain portions of the United States.

As has been pointed out, disturbances of the equilibrium of the atmosphere, in connection with cyclonic storms, take place in a manner more nearly horizontal than vertical, the currents passing spirally inward and upward. In whirlwinds and tornadoes (for whirlwinds may be considered incipient tornadoes) the peculiarity of this disturbance is that it occurs in a manner more nearly vertical than horizontal. Since tornadoes, hail-storms, and thunder-storms are all in the same advance quadrants of low areas, and all likewise travel with greater velocity than the general storm centre, it appears probable that the tornado is an intense development of thunder and hail-storm conditions, in which the enormous force generated by the disruption of very unstable atmospheric conditions is applied to the development of violent whirlwinds, instead of spending itself in the formation of hail or in the inducing of violent and opposing electrical conditions.

Conclusions relative to the paths and characteristics of American tornadoes have been largely drawn from



Edmonton
Battleford
Lytton
New Westminster
Victoria
Humboldt
Olympia
Spokane Falls
Regina
Minnecosa
Ft. Benton
Ft. Assinniboine
Ft. Shaw
Ft. Maginnis
Dayton
Lewiston
Ft. Missoula
Poplar River
Portland
Umatilla
Helena
Ft. Buford
Ft. Stevenson
Roseburg
Billings
Ft. Keogh
Bismarck
Ft. Ellis
Ft. Custer
Ft. Yates
Tornadoes
Eagle Rock
Deadwood
Ft. Bennett
Huron
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Yankton
practically
Salt Lake City
Cheyenne
Sacramento
North Platte
San Francisco
Denver
Pioche
Visalia
unknown.
W. Las Animas
Dodge City
Los Angeles
Santa Fe
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Tucson
Silver City
Denison
El Paso
Ft. Concho
Ft. Stockton
San Antonio
Eagle Pass
Indianola
Brownsville

istribution of
all recorded
Tornadoes
from
1794-1881
Anticosti
Father Pt.
Chatham
Sidney
Halifax
Quebec
Eastport
Yarmouth
Rockliffe
Montreal
Burlington
Mt. Washington
Portland
Prince Arthur's Landing
Duluth
Marquette
Parry Sound
Kingston
Mackinaw City
Escanaba
Alpena
Saugeen
Toronto
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
New Shoreham
Milwaukee
Detroit
Erie
Williamsport
New Haven
Dubuque
Chicago
Toledo
Cleveland
New York
Sandy Hook
Des Moines
Davenport
Sandusky
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Less than
Lynchburg
Norfolk
Cape Henry
Springfield
Kittyhawk
Cairo
Knoxville
Charlotte
Hatteras
Nashville
Chattanooga
Ft. Macon
Memphis
Wilmington
Smithville
Little Rock
Starkville
Atlanta
Augusta
Charleston
over 30
Vicksburg
Montgomery
Savannah
Jacksonville
New Orleans
Pensacola
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba

the studies of Lieutenant John P. Finley, Signal Corps, whose researches and compilations have elucidated some points before unknown or doubtful, and no other person can be accorded greater credit for collecting and arranging data respecting these storms. Finley's researches and collection of data have shown clearly what had been occasionally noted before, that tornadoes do not occur in the immediate vicinity of the centre of a cyclonic storm, but that they bear, however, a definite and tolerably fixed relation to the centre, and occur at a distance of several hundred miles to the southeast of such centre. Marked by sharp, decided contrasts of temperatures and dew-points, preceded by warm, southerly, and followed by cold, northerly winds, these areas of low pressure lie on the northwestern edge of the tornado region. Tornadoes always occur in connection with strong warm winds, while the atmosphere is not only nearly or quite saturated, but also, from its high temperature, contains an abnormally large amount of aqueous vapor.

It appears certain that a state of unstable atmospheric equilibrium exists, which most likely is due to, or coexistent with, very rapid diminutions of temperature with altitude, thus causing *vertically* very large temperature gradients and marked contrasts of vapor conditions. In such case, the presence of strong, warm, moist winds produces conditions wherein the strata of the lower atmosphere is liable to sudden and violent changes. In connection with such rapid transference of air, it requires only a slight predisposing cause to set up a gyratory motion, and thus induce violent winds, known as tornadoes. When this current is once set in motion, it naturally propagates itself along such line and in such direction as similar unstable atmospheric conditions may chance to then prevail. It is noticeable that this gyratory motion, as indicated by the general formation of the tornado cloud, forms in the upper air strata and gradually descends to the earth; thus affording proof that the gyratory motion is initiated in the upper air strata, where the air currents are necessarily of far greater velocity than at the surface of the earth, and the unstable conditions naturally more marked than below.

According to Ferrel, the funnel-shaped cloud—which is characteristically tornadic, and is seen suspended from the lower surface of the undisturbed stratum of clouds—is the water-spout which every tornado must have in its central part.

It is also possible that a tornado is the extending downward of the violent movements of the atmosphere which normally exist in the upper air strata. The velocity of the winds on Mount Washington causes us to infer that it is not unreasonable to expect that, in connection with severe cyclonic storms, the winds at the centre of a severe storm blow, at an altitude of five or six thousand feet, with velocities differing not far from those occurring in connection with tornadoes.

Ferrel believes, and with good reason, that a tornado cannot occur unless there is both a state of unstable equilibrium of the air and a gyratory motion with reference to a centre; and when these principal conditions obtain, the slight initial disturbance to cause the tornado is rarely wanting.

As has been set forth in preceding chapters, the progressive motion of cyclonic storms depends largely, if not entirely, upon the velocity and direction of upper air currents. It has also been stated that conditions of cloud and rain, which engender or facilitate a cyclonic storm system, are far in advance of the centre, generally toward the east. It thus seems possible that the centre of the cyclonic storm does not advance across the country in a vertical position, but, as advanced by Ferrel, rather at a marked inclination, the upper portion of the storm being considerably in advance of the storm centre at the surface of the earth. Such an inclination to the centre of the storm would facilitate severe local storms or tornadoes at a considerable distance in advance of the storm itself, and since such violent storms do occur locally in advance of all violent cyclonic storms, it may be possible in case of tornadoes that the inclination is very marked. Probably these storms occur in the southeasterly quadrants with greater violence, as tornadoes, simply because the larger amount of aqueous vapor in the air causes conditions more marked and unstable than could occur in the northern or western quadrants.

From what has been written the reader may correctly infer that the cause and development of tornadoes involve some points not yet definitely elucidated.

The months of greatest tornado frequency in the United States, as shown by Finley, are May, April, June, and July, in order named. The hours of greatest frequency during the day are from 3.30 to 5 P.M., just after the warmest part of the day, when warm ascending air currents are most liable to meet cooler descending ones.

In the United States 3000 persons have been killed and as many more injured by these storms. As far as the data goes, the loss of life has been greatest in relative order in States as follows: Missouri, Mississippi, Iowa, Illinois, Minnesota, Wisconsin, and Ohio. The loss of property aggregates scores of millions of dollars, and has been fixed, in round numbers, as follows: Ohio, over eight millions of dollars; Minnesota, six millions; Missouri, three millions; Mississippi, two millions;

Iowa, one million and one half; Wisconsin, over one million.

LIST OF TWENTY-FIVE OF THE MOST DESTRUCTIVE TORNADOES IN THE UNITED STATES.

State.	County.	Date.	No. of Persons Killed.	No. of Persons Wounded.	Buildings Destroyed.	Value of Property Destroyed.
Miss. .	Adams.............	May 7, 1840.	317	109	....	$1,260,000
Miss. .	Adams.............	June 16, 1842.	500	....	....	....
Ala.. .	Colbert	Nov. 22, 1874.	10	30	100	....
Wis . .	Iowa..............	May 23, 1878.	30	...	...	....
Mo. . .	Ray................	June 1, 1878.	13	70	100	....
Conn .	New Haven........	Aug. 9, 1878.	34	28	160	2,000,000
Mo. . .	Barry, Stone, Webster and Christian.	April 18, 1880.	101	600	....	1,000,000
Miss. .	Noxubee	April 25, 1880.	22	72	55	100,000
Texas.	Fannin	May 28, 1880.	40	83	49	....
Iowa .	Poweshiek..........	June 17, 1882.	100	300	260	1,000,000
Minn..	Brown..............	July 15, 1881.	11	65	300	400,000
Mo. . .	Henry and Saline...	April 18, 1882.	8	150	51	150,000
Miss. .	Kemper, Copiah, Simpson, Newton, and Lauderdale...	April 22, 1883.	51	200	100	300,000
Wis . .	Racine............	May 18, 1883.	16	100	52	175,000
Minn .	Dodge and Olmstead	Aug. 21, 1883.	26	80	400	700,000
Ark...	Izard, Sharp and Clay............	Nov. 21, 1883.	5	162	60	300,000
N. C..	Richmond and Harnett.	Feb. 19, 1884.	18	125	55	....
Dak...	Miner, Lake and Minnehaha.......	July 28, 1884.	15	18	100	....
Minn.. Wis...	Rock, Hennepin, Ramsey and Washington.......... St. Croix, Polk, Barrow, Chippewa and Price	Sept. 9, 1884.	6	75	305	4,000,000
N. J..	Camden............	Aug. 3, 1885.	6	100	500	500,000
Ohio .	Fayette..........	Sept. 8, 1885.	6	100	300	500,000
Minn .	Benton and Stearns..	April 14, 1886.	74	136	138	385,000
Ohio .	Greene and Huron..	May 12, 1886.	27 30	....	 85	1,000,000 300,000
Kan...	Prescott...........	April 21, 1887.	20	237	330	1,000,000

Chart No. XXIV. shows the distribution of tornadoes in the United States. This chart, originally prepared by Lieutenant Finley, shows the distribution only in a general manner. Data of this kind is always incomplete, especially in the thinly settled portions of the country, and so the lines of equal frequency are somewhat uncertain ; but there can be no doubt, however, that the relative frequency is greatest in the valleys of the lower Missouri and of the upper Mississippi. It has been demonstrated by Ferrel that this region is theoretically liable to tornadoes owing to the counter-currents of cold air from the northward, and warm, very moist southerly winds from the Gulf of Mexico, which latter currents tend to cause an unstable state of the atmosphere.

Finley has pointed out that tornadoes rarely if ever occur west of the 100th meridian, in which regions the lack of aqueous vapor and the want of intensity in other phenomena of cyclonic storms furnish sufficient reasons for their non-existence.

The tornado follows a definite path, which, as a general rule (about eighty per centum), is from the southwest toward the northeast. About ten per centum move from northwest to southeast. The path of greatest violence varies, as a general rule, between one hundred and six hundred yards in width, and from one to fifty miles in length. The progressive movement of the tornado is very rapid, being rarely under twenty miles an hour or over fifty miles, and the time taken in the passage of the immediate centre is between five and ten minutes.

The violence of the tornado is too familiar to need elaboration. Winds which uproot or twist off the largest trees, unroof or destroy the most stable buildings, lift the heaviest locomotives from the railway track, and even upraise and carry from their foundations large iron bridges, can be better imagined than described.

One of the most remarkable and best known tornadoes in the United States is the Marshfield, Mo., tornado, which occurred April 18th, 1880. The town of Marshfield was nearly destroyed, and ninety-two of its inhabitants perished from this terrible storm. On February 9th, 1884, an unparalleled series of tornadoes occurred from Mississippi, Tennessee, Kentucky, and Illinois, eastward to Virginia, North Carolina, South Carolina, and Georgia. There were more than sixty separate tornadoes after 10 A.M. of that disastrous day. Over ten thousand buildings were destroyed, eight hundred people killed, and twenty-five hundred wounded.

Waterspouts not infrequently occur at sea, and these phenomena may be considered as incipient tornadoes of comparatively feeble force. They are sufficiently powerful at times to disable or destroy vessels, though such cases are comparatively rare.

CHAPTER XVIII.

HAIL, THUNDER, AND DUST STORMS.

In addition to regular cyclonic storms and tornadoes, which have been discussed in preceding chapters, there are other atmospheric disturbances, generally known as local storms, such as hail, thunder, and dust storms. These atmospheric disturbances are almost invariably connected with the passage of some cyclonic centre across the country, and can be considered local only to the extent that the violent manifestations do not cover the entire area of the country, but are experienced in patches or bands.

Professor Hazen's investigations show that both hail and thunder storms have in general the same relative position to areas of low pressures as do tornadoes. Hail-storms are most frequent in the southeast quadrant, about two hundred miles in advance, while thunder-storms without hail are about twice as far distant from the low centre.

Storms of hail, unlike those of rain, do not cover the country universally, but the hail-storm follows, like the tornado, a path whose breadth is very narrow compared with its length. It very frequently occurs that hail-storms pass over certain districts in parallel bands, between which rain only and no hail falls.

Perhaps the most remarkable hail-storm on record was that of July 13th, 1788, which passed from Touraine, France, to Belgium. The mean interval between the bands was twelve miles, while the western hail band had a width of ten miles and a total length of 420 miles, and the eastern band a width of five miles and a length of 500 miles. Over one thousand communes in France suffered from this storm, and property valued at $5,000,000 was destroyed.

On May 9th, 1865, a severe hail-storm followed a path from forty-five to sixty miles in width, from Bordeaux, France, to Belgium. In the arrondissement of St. Quentin hail fell in such quantities that it did not disappear for over four days. In one place a mass of ice, which formed from the hail, was said to be a mile and a quarter long and about two fifths of a mile broad, amounting to 21,000,000 cubic feet.

Dr. Buist, in the British Association report for 1855 on hail-storms, points out that in India hail-storms occur most frequently in the driest months, over fifty per cent falling during March and April. The magnitude of the hail-stones and the severity of the storms of India is shown by that which occurred in the Himalayas north of the Peshawur, May 12th, 1853, when eighty-four persons and 3000 oxen were *said* to have been killed. On May 11th, 1855, a storm occurred at Naina Tal, 29° 20′ N., 80° E. Stones as large as cricket balls fell, some weighing ten ounces, and one or two more than 1.5 pounds avoirdupois, the circumferences varying from nine to thirteen inches.

The most fatal hail-storm on record is that of April 30th, 1888, at Moradabad, India. There is no question that this storm directly resulted in the loss of more than two hundred and thirty human lives. The following account, by J. S. MacIntosh, C.S., was furnished the author through the courtesy of John Eliot, Esq., Meteorological Reporter to the Government of India :

" A terrific storm of hail followed, breaking all the windows and glass doors. The verandas were blown away by the wind. A great part of the roof fell in, and the massive pucca portico was blown down. The walls shook. It was nearly dark outside, and hail-stones of an enormous size were dashed down with a force which I have never seen anything to equal. As soon as the storm abated I went out. . . . There were also long ridges of hail on the higher ground (of the race-course) one or two feet or more in depth. . . . There is not a single house in the civil station which did not sustain the most serious injury. . . . The really destructive hail seems to have been confined to a very small area, about six or seven miles around Moradabad.

"Two hundred and thirty deaths in all have been reported up to the present time. The total number may be safely put as under two hundred and fifty. The majority of the deaths were caused by the hail. Men caught in the open and without shelter were simply pounded to death by the hail. Fourteen bodies were found in the race-course. . . Most of the deaths were on the bare and level plains round the station, where people were caught unawares. More than one marriage party were caught by the storm near the banks of the river, and were annihilated. No Europeans were killed. The police report that 1600 head of cattle, sheep, and goats were killed."

Mr. Eliot was of the opinion that those who perished were not killed directly by the blows of the hail-stones, but by being knocked down by the wind, were buried in the hail, and perished through the combined effects of cold and exhaustion.

On June 10th, 1879, a succession of violent hail-storms passed through Eastern Kansas and Western Missouri, over a territory 340 miles long by 260 miles in breadth, travelling from northwest to southeast, in narrow belts of from six to ten miles in width.

The following dates indicate the most remarkable and destructive hail-storms that have occurred in the United States:

July 30th, 1877.—In the Yellowstone Valley hail-stones as large as oranges fell. They perforated the *tepees* of the Crow Indians and killed a large number of ponies.

June 5th, 1879.—Terrific hail-storms occurred at West Newton, McKeesport, Library, Parker, Philadelphia, and other places in Pennsylvania; Waltham, Mass.; Hudson, Mich.; Atco and Vineland, N. J.; Cleveland, North Lewisburg, and Norwalk, O.; Fort Hale and Yankton, Dak. At Yankton the hail was from nine to twelve inches deep, while the path of the storm was two miles wide in a direction from southwest to northeast.

July 16th, 1879.—Severe hail-storms extended in bands from Central New York eastward, to include the greater parts of Massachusetts, Rhode Island, and Connecticut. At Lanesboro, Mass., stones seven inches in circumference fell.

July 26th, 1880.—Violent hail-storms, with stones from six to ten inches in circumference, occurred in Wisconsin. The path near Waupaca was from south-west to northeast, and two miles wide; near Stevens Point, four miles wide and ten miles long. Lambs and sheep were killed and crops totally destroyed.

June 24th, 1881.—A very destructive hail-storm passed over a section of country, ten miles wide and twenty miles long, in the Arkansas River Valley. All grains, grass, and vines were cut down level with the ground.

July 26th, 1881.—In Cumberland Co., Me., a hail-storm moved from southwest to northeast—path, two miles wide and twenty miles long—the most violent storm since 1833, when a similar storm followed the same path. Stones as large as hens' eggs fell, and in such quantities that twelve hours later drifts two feet deep were visible.

June 2d, 1881.—Very violent hail-storms did immense damage in Illinois. Near Mill Creek the storm path was two miles wide by ten miles long. Near Whitehall the storm passed from northwest to southeast over a track seven miles long and one mile wide. Drifts of hail from eight to twelve inches deep were found the next day, and some of the stones were nearly the size of goose eggs.

June 3d, 1881.—At Lewiston and Asotin, Ida., remarkably severe hail-storms occurred, killing a large number of sheep and fowls, and birds by hundreds.

June 12th, 1881.—Very destructive hail-storms occurred in Iowa, where farm crops were ruined, calves, hogs, and fowls killed, and stock badly bruised. Hailstones, some of which were the size of a man's fist, drifted in places two or three feet deep. The storms were most violent in the counties of Henry, Guthrie, Pottawattamie, Audubon, and Cass.

June 4th, 1882.—A destructive hail-storm occurred east of Freehold, N. J., its path being thirty miles long and half a mile wide.

June 8th, 1882.—At Laredo, Tex., very large hail fell, single stones weighing a pound.

June 16th, 1882.—At Dubuque, Ia., hail-stones fell from one to seventeen inches in circumference, the largest weighing twenty-eight ounces, the size of lemons. These stones were of diverse and peculiar formations, some evidently being agglomerations, as they were covered with knobs and projections, probably formation similar to Fig. 16, C, on p. 79. Other stones were composed of alternate ice-layers of varying shades of color and degrees of transparency. It was reported that these layers had, in some instances, gravel and bits of grass imbedded within them, but probably these foreign substances resulted from contact with the ground where they fell.

August 10th, 1882.—Wyoming Co., N. Y., a severe storm occurred, with a hail belt four miles wide and about forty miles long, and stones as large as hickory-nuts.

During the night of August 7th and 8th, 1883, a very severe hail-storm occurred in Lac and Audubon counties, Ia. In the former county the hail was unusually large, and in such quantities that, in places, it was yet unmelted two days after. Grain was destroyed, small animals and poultry killed. The largest hail-stones measured thirteen inches in circumference, near Gray, Audubon Co., where twenty-one cattle were killed. The drifted hail was said to have covered fence tops and to have delayed railroad trains.

July 8th, 1883.—Severe hail-storms occurred in Davidson Co., Dak. Near Morriston the hail belt was two and one half miles wide and thirty miles long; near Huron, two and one half miles wide and about twenty miles long; both belts extended from northwest to southeast.

June 7th, 1886.—In San Miguel and Lincoln counties, N. M., hail-storms did great damage, killing a number of sheep, cattle, and horses.

June 26th, 1886.—A destructive hail-storm, with a path twenty miles long and two miles wide, passed through Walsh and Grand Forks counties, Dak., destroying all crops and leaving so much hail that it did not all melt within thirty hours.

July 24th, 1886.—Unusually destructive hail-storms occurred in Dakota and Minnesota. Near Grafton the stones were as large as hens' eggs. The path of the storm was five miles wide and thirty long. Quarter of a million acres of wheat were said to have been entirely destroyed in that section alone.

August 10*th*, 1886.—During a storm at Fort Yates, Dak., hail-stones fell as large as three and one half inches in diameter. They were spherical in shape, centre composed of dry, compact snow, outside layer very hard ice with cylindrical protuberances projecting from the sides from one half to three fourths of an inch.

THUNDER-STORMS.

It has been pointed out, by Dr. Meldrum it is believed, that essential elements to thunder-storms are masses of descending cold air, along with other ascending currents of warm, moist air. This theory tends to explain the infrequency of lightning storms in California and Arizona, where the climate is not only dry, but where the atmospheric disturbances are such that descending cold currents are of rare occurrence.

The favoring conditions for thunder-storms depend largely on the current action of the solar heat, as is shown by the fact that these storms, while maintaining their sphere of action at quite uniform distances from the cyclonic centre, die out at nightfall and recommence the next morning.

It is well known, in a general way, that thunder-storms do not occur with the same frequency throughout the United States. As regards the monthly frequency, the winter months have the least and the summer months have the most thunder-storms.

Thunder-storms are most frequent in Florida and the Mississippi and lower Missouri valleys, the average annual number being from thirty-five to fifty. Over the lake region the number falls to twenty, and in New

England to ten annually. To the westward of the Rocky Mountains the annual average number is less than ten for the whole region, while in Southern California one or two years may pass without a manifestation of thunder or lightning.

Electrical discharges which take place between separate clouds, or between clouds and earth, follow an irregular path, taking the route of the least electrical resistance between the separate objects. Franklin's discoveries a century ago proved that these discharges and those from electrical machines are identical in character. Electrical flashes pass with such enormous velocity that one cannot say with absolute accuracy whence or to what point the discharge travels. It is safe to assert that all appearances of lightning, whether distinct flashes or sheet or heat lightning, are coincident with the presence of thunder-storms, the only difference being that in case the flash is below the horizon or concealed by intervening clouds, the spectator sees the reflection of or the illumination caused by the electrical discharge.

The phenomenon known as globular lightning, where globes of fire appear and move very slowly, occasionally exploding with great violence, has not yet been satisfactorily explained.

It is unnecessary to point out the tremendous force exerted by lightning, and its consequent damage done in its passage to the earth. Death most frequently results from the passage of a flash of lightning through a person, but there are exceptions to this rule.

By a phenomenon termed *return shock*, persons are said to be killed without there being any visible flash between their bodies and the electrified cloud. In this case, death is supposed to follow from the person having been fully charged with electricity of an opposite kind to that in the cloud, and when the discharge takes place the electricity quits the body with such violence as to be fatal to the individual.

Dwelling-houses and their contents are believed to be tolerably safe from serious damage when they are properly provided with lightning-rods. An essential point in furnishing a building is that such rod must be perfectly continuous from its highest point to the ground, and to insure this all joints should be soldered or welded carefully. Care must be taken to examine the rods from year to year, and insure that their conductivity is not impaired by rust or corrosion breaking the rod's continuity. The rod must be buried sufficiently deep in the earth to connect with moist soil, preferably with water-mains, springs, or drains, and in being attached to the building should be connected with extensive metal part and adjacent water-pipes.

The question as to whether high buildings, tall trees, and other prominent features of the landscape draw lightning strokes or not, is a mooted one. No doubt exists that these prominent objects, being nearer the thunder-cloud, have consequently greater liability of being struck, since they must more frequently furnish paths of lesser resistance to the passage of the lightning to the earth than do lower objects.

Dr. Hellmann shows that the geological character of the soil has much to do with frequency of lightning strokes, the proportion being one for chalk-bed, seven for clay, nine for sand, and twenty-two for loam. Oaks are most often and beeches least often struck, and nearly always in the clear or at the forest's edge. The risk of houses being struck increases with segregation and height, and is five times greater in the country than in the city districts. In fifteen years' average the number of people killed in Prussia was 4.4; in Baden, 3.8; in France. 3.1: and in Sweden, 3.0.

DUST-STORMS.

In very dry countries during the rainless season local whirlwinds occasionally pass over limited sections, the disturbance being similar to that of a feeble tornado. Such disturbances occur without rain, and, in consequence, columns of dust or fine sand arise. In the deserts of Africa, Arabia, and India these dust-storms are of such violence, that in connection with the high temperatures which often accompany them, they overwhelm and occasionally destroy passing travellers. In the United States such conditions at times prevail, but never with any great violence, in the sandy deserts of California and Arizona.

After prolonged dry spells such storms occasionally occur immediately over or to the eastward of regions covered with scanty vegetation.

On March 26th, 27th, 1880, unusually violent wind storms occurred in Nebraska, Kansas, Iowa, Indian Territory, Texas, and Missouri. As a rule, very little rain fell during these storms, so that the air was filled with dust and fine sand to such an extent that the sun was almost obscured. Professor Nipher reported that all Missouri, except the extreme southern part, suffered from these phenomenal conditions. "The atmosphere," he says, "was filled during the whole day (27th) with a fine grayish dust, which in Western Missouri and Eastern Kansas was so dense as to obscure the light of the sun and to render objects invisible at a distance of from 100 to 300 yards." At Howard, Neb., dust gathered in drifts varying from twelve to twenty inches in depth.

The peculiar atmospheric conditions known as dry fogs, or those where the sun is partly obscured without the intervention of clouds, arise from dust, smoke, or other impurities which have been undoubtedly raised to the upper strata of the atmosphere through the action of cyclonic winds, and which, owing to their minuteness and small weight, remain for days or weeks in the atmosphere, upborne by continuing currents.

The haze peculiar to the season known as Indian summer is simply a dry fog, where the impurities in the atmosphere remain a long time, owing to the absence of rain. The greater part of the impurities are smoke from prairie or forest fires. The most remarkable condition of dry fog in the United States was that which was experienced between September 1st and 10th, 1881, between meridians 67 and 87 W. and the 40th and 45th parallels. Prairie and forest fires had raged with very destructive violence throughout northern Michigan and portions of Canada, from which this smoke drifted slowly eastward. The intensity of these conditions was the greatest on September 6th, at which time, over the Atlantic States, from New Hampshire southward to North Carolina, the sun was very largely or entirely obscured by the haze in the atmosphere. In Connecticut, Massachusetts, Rhode Island, and Vermont the absence of light was such that business was largely interfered with, and artificial light, even at midday, was rendered necessary in public and private places of business. Many people were much alarmed by the peculiar atmospheric conditions. At Salem, Mass., the day was the most remarkable one since the famous dark day of May 19th, 1780.

CHAPTER XIX.

DROUGHTS AND HEATED TERMS.

It is difficult to say definitely what is a drought, as meteorologists have not agreed upon this point. It is evident that the absence of rain for a single month, or its falling in very small quantities, does not necessarily constitute a drought, since in certain sections of the United States, such as California, Nevada, and Arizona, certain months are rainless and others are marked only by passing showers.

It would seem advisable that some method should be followed in describing droughts, and the author would suggest that the term be used only in connection with those sections where the average rainfall exceeds one inch in each month, and that the scale of severity should increase from 1 upward.

From an examination of the records it appears that droughts are very severe whenever the rainfall for one or more months is less than fifty per centum of the average amount. It is suggested that the drought unit indicate a deficiency of rainfall equal to twenty-five per centum for a single month, the deficiency to be determined with reference to the average monthly amount during the time in which the drought prevails.

Under this scale the very severe drought of 1887 in the northwestern part of the United States would be indicated by the numbers 7 to 14, according to locality and rainfall deficiencies.

It is needful to treat the subject of droughts together with that of prolonged and excessive heat, since this last condition never prevails in the United States except as a result of deficient precipitation, either over the regions in question or those immediately to the westward or southward of it.

The excessive heats of August, 1876, from Maine southward to Virginia, and westward to Ohio, were coincident with a rainfall varying from one-fourth to one half of the normal amount for August. The underlying cause of scanty rainfall in the northern part of the United States likewise increases the temperature unduly, by inducing continued southern winds. This cause is the slow passage of feeble cyclonic storms across the United States in paths of very high latitude. In August, 1876, to the eastward of the 95th meridian, no cyclonic storm passed over the United States in latitudes to the southward of the 45th parallel.

In connection with the unparalleled heated term of July and August, 1881, it is to be noted that in the former month only one of the four cyclonic storms moved eastward in a path to the southward of the 46th parallel, and in August no storm crossed the country to the eastward in a path to the southward of the 46th parallel. Besides, the five storms of the latter month were all of very feeble character, except one in Southern Florida.

To summarize briefly, prolonged heated terms result (1) from conditions of summer drought, where the parched earth readily receives heat from the sun, which is radiated to surrounding objects without any considerable quantity of it being spent in transforming into aqueous vapor the usual moisture at the surface of the earth, caused by the average rainfall; and (2) by such distributions of atmospheric pressure as cause, over the districts affected, the prevalence of warmer winds from more southerly latitudes or from drought-stricken districts. In the United States this distribution of pressure looks to the slow passage of areas of low pressure eastward across the extreme northern part, thus inducing from the Gulf of Mexico to the northern boundary southerly or southwesterly winds, which, being originally of high temperature, still retain their heat and also lose their moisture in passing over the drought districts.

During July and August, 1876, there was a very severe drought from Maine southward to Virginia, and westward to Pennsylvania and Michigan. Crops were seriously damaged, wells and streams became dry, and industrial establishments were closed. From the early part of July to the end of August, over New England, New York, and Pennsylvania, the rainfall averaged only about an inch, which is less than one fourth of the usual amount.

The most extensive, prolonged, and disastrous drought of the United States is probably that of July, August, and September, 1881, which affected the entire country east of the Mississippi River. During July and August the drought was also bad in Kansas and Arkansas. During August less than one eighth of the usual amount of rain fell in the Ohio Valley, less than one third in the Middle Atlantic States, and only about two fifths in New England and the region along Lakes Ontario and Erie.

By the early part of September a lamentable condition of affairs existed to the eastward of the Mississippi River as far northward as Illinois and New York. The wells, cisterns, and springs that had never before gone dry were exhausted, and nearly all the rivers of the country were at the lowest state ever known. Pastures were parched and crops badly injured or entirely destroyed. Water was so scarce in many places that cattle suffered greatly for want of it, and numerous manufacturing industries were sadly interfered with or entirely discontinued. In McKean and Alleghany counties, N. Y., one thousand oil-wells shut down for lack of water to run engines. On the New York Central Railroad freight trains were seriously delayed by lack of water for steam, and in scores of towns and cities manufacturing industries were run on short time, or greatly inconvenienced. Many cities were obliged to draw their water-supply from new sources, and New York City was compelled to draw upon the upper reservoirs in Putnam Co. and the storage reservoirs at Lake Mahopac.

In 1886 a severe and prolonged drought prevailed in Northeastern Dakota and Northwestern Minnesota. It commenced about the middle of June, and lasted until the end of October, and its injurious effects were supplemented by unusually high temperatures. During June and July the limits of the drought were more extensive, and included a considerable part of Nebraska and Kansas, Northern Iowa and Western Wisconsin, and nearly all of Minnesota. Professor Snow says that this drought, with only 2.85 inches of rainfall from June 26th to September 16th, a period of eighty-one days, was of the same duration and the only serious one in the vicinity of Lawrence, Kan., since that of 1874, when in eighty days only 2.19 inches of rain fell.

The drought of 1887 was one of the most prolonged as well as severe droughts ever experienced in the United States. During the six months from May to October, 1887, the rainfall was only from sixty-five to seventy-five per centum of the average over Kentucky, Ohio, Michigan, Indiana, Illinois, Missouri, Iowa, and parts of Wisconsin, Minnesota, Nebraska, and Dakota. Less than one half the usual rain fell in these months over Central Ohio, along the Ohio Valley from Louisville to Cairo, and parts of Illinois and Wisconsin.

In the early year the drought covered a much larger area, being also severe over Kansas, Indian Territory, and Texas, but was broken in Kansas about the end of April, and in other sections during May.

HEATED TERMS.

In occasional summers extensive portions of the United States are subject to excessive and dangerous temperatures, which, when prolonged for several days, are known as heated terms.

In July, 1876, there were continued high temperatures during the greater portion of the month throughout the United States east of the Rocky Mountains, the heat in many places becoming so intense as to produce fatal results, to cause the suspension of business, and to augment the death-rate of many of the large cities to the highest percentage. Temperatures of or near 100° occurred on several successive days from Jacksonville and Montgomery northward to Pittsburg and New York.

In July, 1878, there was a heated term almost unprecedented in its severity, continuance, and fatal results, from Missouri and Iowa eastward to New England and the Middle States. From the 2d to the 5th, inclusive, very high temperatures prevailed in New England and the vicinity of New York City, and in these sections over fifty sunstrokes occurred, many of which were fatal. From the 12th to the 22d the country was free from the passage of any low-area storms, except slight depressions along the northern lakes and the St. Lawrence Valley, the result of which was to induce warm and dry southerly winds over the eastern part of the country.

During this period the hottest days of the year naturally occur, but their severity was augmented by the conditions above noted, so that excessively high temperatures, both night and day, prevailed. The intensity of the heat was such that business was partly suspended, and in ten days over five hundred cases of prostration from sunstroke occurred, a large portion of which were fatal. One hundred and sixty-three persons were said to have died in St. Louis alone from sunstroke, and probably throughout the country 300 persons perished from the direct effects of the intense heat, while the increased death-rate in the large cities indicated that hundreds of others died indirectly from the prolonged high temperature.

From September 12th–15th, 1882, a succession of very hot southerly and southwesterly winds was experienced over Kansas and Missouri, during which temperatures ranging from 100° to 110° were recorded. Vegetation was burned up, and the air at times was filled with clouds of suffocating dust.

Professor Snow says: "During these simoons (at Lawrence, Kan.) the air was excessively dry, the relative humidity sinking to seven per centum the afternoon of the 12th. The fierce dry heat burned the foliage of trees, so that they crumbled to powder at a touch."

The cause of these burning winds is easily found in the fact that in eastern Colorado, as indicated by the observations at Las Animas and Denver, Col., no rain fell during September, and at Lawrence, Kan., only 0.10 in over a month immediately prior to these winds, so that the country to the west and south was parched by fierce droughts and the burning sun.

In June, 1877, from the 8th to the 12th, excessively high temperatures occurred in California, ranging from 93° at San Diego to 114° at Yuma and 122° at Spring Valley. It is an interesting fact that during this period ice formed within 600 geographical miles of these extreme temperatures, at Cheyenne, Wyo.

In the Gila Valley, Ariz., over an area of thousands of square miles, the monthly mean temperature of the month was from 93° to 94°. At Fort Yuma the daily maximum temperature did not sink any day below 103°, and the mean was 110° for the month. For eleven consecutive days the lowest temperature was never below 77°, while the highest day temperatures ranged from 106° to 118°.

One of the most remarkable of these prolonged periods of high temperatures in the United States was from July to September, 1881. During July there was a prolonged heated term in the Ohio and Central Mississippi valleys. The temperature reached or exceeded 100° for several successive days, and hundreds perished, directly or indirectly, from the heat. During these days the sufferings of the inhabitants of the cities of these sections were beyond description. In Cincinnati two hundred and thirteen died of sunstroke that week, at St. Louis, thirty, and at Dayton, O., thirty. In August the continued great heat was yet further augmented between the 5th and the 13th, from Missouri and Iowa eastward to New England, but fortunately was not attended with fatalities to the same extent as in July. In September the rainfall was larger than usual in the Mississippi Valley, so that the area of excessive heat was translated considerably to the eastward, the greatest heat occurring in New England, New York, New Jersey, and Pennsylvania.

The immediate Pacific coast region is noted for its cool, equable summer temperatures, but in several instances the desert wind of California has seriously affected the immediate coast. The most remarkable case, that of June 17th, 1859, was at that time said to be the most wonderful visitation of this character in the Pacific coast region for thirty years. At San Francisco on that date the thermometer is said to have registered a rise in the temperature from 77° to 133°, with a burning northwest wind, which fortunately lasted for a few hours only, the thermometer registering 77° at 7 P.M. At Santa Barbara, on the same day (in the afternoon), a strong easterly wind set in, during which the burning air was filled with dense clouds of fine dust, which caused intense suffering, and drove every one to the nearest shelter. The fruit was all destroyed, and although the burning blast lasted but a few hours, yet animals, such as calves, rabbits, and birds, died from the effects. The temperature was said to have reached 133° at Santa Barbara, 102° at San Diego, and 117° at Fort Yuma.

It seems possible that the frequency and intensity of such visitations have diminished on the Pacific coast, since Tennant's record of hot days (classing as such those on which the temperature rose to 80° or above at San Francisco) indicates that their annual number have very materially diminished since 1859. For seven years prior to 1859 such days averaged thirteen yearly, and since that time, up to 1871, the average yearly number is but four. The immense quantity of land placed under irrigation and the vast increase in vegetation are obvious reasons why there should be some diminution in this respect.

The provoking cause of *desert* winds must be the passage of a low-area storm parallel with and a short distance off the Pacific coast, thus causing a draught of desert air to the westward. It is more than probable that the temperatures enumerated above may be somewhat in excess, partly owing to possible error of the thermometer and partly through their imperfect exposure. There is no doubt, however, but some of the highest temperatures in the world must obtain on Mojave and Colorado deserts, so that in summer any strong easterly wind from these sections must during its prevalence raise enormously the temperature at coast stations.

The fatal effects of these heated terms are not shown alone by deaths through sunstroke, but more emphatically, if less obviously, by the increased percentages of death-rates from all causes. It has been stated that in July, 1876, the death-rate of many cities of the United States reached very high percentages, but even then they do not attain to the excessive mortality of some other countries, under similar conditions.

In Lower Egypt, a severe and prolonged heated term prevailed from June 15th to July 25th, 1888, during which the weekly mortality at Cairo increased from a little above forty to ninety-seven and two tenths, and in one quarter to 126 per 1000.

This illustrates the importance of preserving such natural conditions as will render heated terms difficult and serve to modify their existing conditions ; and in no way can this be better done than by the cultivation and conservation of growing vegetation, especially of woodland and forest, whose action in this direction is mentioned on page 156.

CHAPTER XX.

MISCELLANEOUS PHENOMENA.

THERE are a number of phenomena and physical conditions, connected more or less with climatology and meteorology, which are very interesting and important in themselves, but cannot be more than alluded to.

SEA TEMPERATURES.

Perhaps the temperature of the surface water of the sea possesses the greatest interest and importance of the miscellaneous phenomena. Its effects have been briefly alluded to in the chapter on the distribution of temperature.

The diurnal range of surface sea temperatures is small, the minimum occurring about sunrise and the maximum near noon.

The temperature of the surface of the ocean has been observed at 2 P.M. daily for many years along the Atlantic coast. The difference between the highest and lowest average monthly temperatures amounts to 29° at Portland, Me., and Jacksonville, Fla., from which places it increases to the southward and northward, respectively, to 42° at Chincoteague, Va. The ranges at Key West and Eastport are nearly identical, being 16° and 18° respectively, while the average difference between the months in the Gulf of Mexico is about 30°.

The maximum monthly temperature occurs in the Gulf of Mexico and from Key West northward to Chincoteague in July, and the mean gradually diminishes between the two stations named from 87.4°, at the southern, to 80°, at the northern. From Cape May to Portland the maximum average prevails during August, and falls to 61° at the last-named station, while at Eastport the highest temperature is but 50.6° in September. The lowest average temperatures occur in January as far northward as Atlantic City, and thence to Portland in February. As exceptions, Key West has the lowest temperature, 71.2°, during December, and Eastport, 32.7°, during March.

EARTH TEMPERATURES.

The temperature of the earth is not generally considered as of great meteorological importance, but observations regarding the temperature of surface soils, in which the staple crops of the country grow, would be theoretically valuable to the agriculturist.

The earth is a bad conductor of heat, so that at a considerable depth, say twenty feet, its maximum temperature occurs not far from December, and its minimum near June, the dates varying according to soil and latitude. At a certain point, dependent on the annual mean temperature and the character of the soil, the effect of the sun's heat disappears, and the influence of heat from the interior of the earth is felt. The increase of temperature has been variously placed from 1.4° to two degrees for each hundred feet of descent.

At Point Barrow, Alaska, the temperature of the earth, at a depth of thirty-seven feet below the surface, remained for months constant at 12° Fahr. Assuming an increase of temperature equal to one degree in about fifty feet—a low estimate—the earth is there frozen to a depth of over one thousand feet. At Jakutsk, Siberia, the earth was found frozen at a depth of 382 feet.

It is probable that in the northern parts of Minnesota, Dakota, and Montana frost occasionally penetrates in very severe winters to a depth of seven or eight feet, since at Binscarth, Manitoba, 50° 40′ N., 101° W., frost has been found at nine feet.

ATMOSPHERIC ELECTRICITY.

Atmospheric electricity, so closely connected with thunder-storms, deserves and is receiving attention from scientists of high standing. It has been satisfactorily established that rapid changes in electrical potential take place in advance of and during the progress of rain and thunder storms, but up to this time no definite march of electrical phenomenon has been outlined as having an important bearing on weather or weather forecasting.

OZONE.

Similarly, that *allotropic* condition of oxygen known as ozone has excited great interest, owing to its important bearing on health, through its rapid powers of oxidation facilitating decomposition of organic substances. No satisfactory or standard method of making ozone observations has yet been adopted, so that the few observations made are impaired in value, as they are not at all comparable.

OPTICAL PHENOMENA.

There are various optical phenomena constantly recurring in the atmosphere which give pleasure to the spectator by their wealth and variety of color, but do not have any very important bearing on meteorology.

The glowing color of the western sky at sunset, through our fine American weather almost of daily occurrence, is the local sign for the weather of the coming morn which is most regarded and relied on.

A sunset marked by beautiful and slowly fading colors, from white lights through orange to the reds, as its final accompaniment, is considered to presage that the coming day will be fair. This belief is verified to a great extent, since such weather occurs in three fourths of the cases, but no final and scientific reason has been assigned therefor, and the subject is of so complicated a character that it is not fully understood.

It has been pointed out that when the sun is very low in the heavens, its rays traverse a much longer path through the atmosphere to reach an observer than when the angle of inclination is greater. The air disperses the rays of light somewhat as does a prism, and, as is known, the aqueous vapor and air strata, of varying quantities and densities, change the sky colors at sunset through various processes, such as absorption, diffraction, refraction, interference, and reflection. When the atmosphere is quite free from violent disturbances, and the aqueous vapor is not only present in quantities below the average, but is also quite regularly distributed, its reduced quantity and comparative homogeneity permit the various optical processes of the solar rays to proceed slowly, regularly, and gradually, until they end in the red glows. When conditions of violent disturbance, such as precede storms, obtain in the upper atmosphere, it is reasonable to assume that such varying conditions of air density and vapor must cause the modifying process to proceed irregularly to such an extent as to produce at sunset the cold, harsh contrasts of cloud color which are viewed as preceding rain.

Scott has pointed out that a knowledge of these conditions is of value, largely owing to the fact that the march of weather phenomena is from west to east in the Northern Hemisphere.

Rainbows have no meteorological significance, being produced simply by reflection and refraction from drops of water, and may be seen in the spray of fountains or waterfalls. Fogbows and lunar rainbows are similar phenomena, but of rarer occurrence.

The observer of a rainbow well knows that he is always situated exactly on a line between the sun and the bow itself, which line, if extended from the sun through the observer's eye, would end in the very centre of a circular rainbow. There may be two bows—the *primary*, with the *red outside*, and the *secondary*, with the *red inside.* Inside the primary bow or outside the secondary bow may be other supernumerary bows of red and green alternately.

Halos are circles of prismatic colors around the sun or moon, and generally have radii of 22° or 45°, while coronas are faintly colored concentric circles of very small diameter, with radii from 4° to 8°, immediately around the moon. Coronas have the blue color nearest the moon, while halos have the red color nearest. Coronas arise from the passage of light cirrus clouds or aqueous vapor, otherwise invisible, before the moon, thus interfering with the rays of light as they pass by the vapor drops. Halos are formed by the refraction and the reflections of the solar rays from ice crystals of cirrus clouds, or from ice particles suspended in the air.

In the author's experience in the arctic regions, at Fort Conger, Grinnell Land, solar halos of great beauty and remarkable brilliancy were frequently observed during the very cold, clear days of early spring. In such cases double halos, with four, five, or six mock suns of great splendor, were not infrequent. In these cases refraction and reflection of the sun's rays were from minute spiculæ of ice, which, suspended in the air, were commonly known to the men of the expeditionary party as "frost in the air." At times the solar halos and mock suns were visible against a background of a high hill less than a mile distant.

These halos by observation formed exactly under conditions when, according to Scott, "they would be theoretically producible if the rays were refracted through minute crystals of ice floating in the air in all sorts of positions."

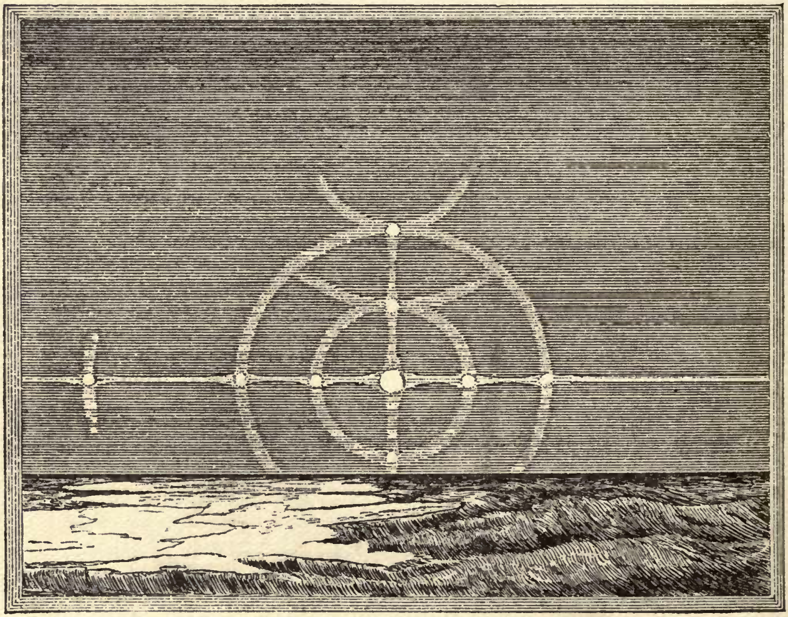


FIG. 32.—LUNAR HALO AT FORT CONGER, FEB. 1, 1882.

On February 1st, 1882, at Fort Conger, the author saw a most remarkable lunar halo, of which an imperfect idea is given by Fig. 32, when the moon was about 25° above the horizon. The circles of 22° and 46° were perfect to the horizon, and were both tipped with contact arches. Six mock moons were present

—two on either side of the true moon and two above it—all of which showed brilliant prismatic colors, very like the clear, distinct colors seen in rainbows. Spears of light extended from the moon vertically, reaching downward to the horizon and upward to the outer circle. In addition, a narrow streak of clear, white light extended from the moon horizontally on both sides completely around the entire horizon, at an altitude of 25°, the same as that of the moon itself. At times a faint mock moon without rainbow colors was to be seen at 90° distant from the moon, being in the north, while the moon itself was in the east, and a second faint one under the moon, so that eight mock moons were visible at one time. The halo lasted an hour, the number of moons varying during that time.

Halos are supposed to indicate coming rain or snow, and Professor Laughlin, a voluntary observer in Tennessee, reports that from observations taken during 1884 and 1885, eighty-six per centum of halos observed and ninety-three per centum of coronas were followed by precipitation within three days.

Probably the most remarkable series of solar halos seen in the United States were those from December 29th-31st, 1880, in the Ohio, upper Mississippi, and lower Missouri valleys. At that time the temperature of these sections was below zero, Fahrenheit. The halos were frequently double, being of 22° and 46° radii, with brilliant contact arches. Generally the prismatic colors showed with great distinctness, and mock suns, varying in number from two to five, were frequent.

The images of the sun—often showing prismatic colors—at the intersecting points of the circle are called *parhelia*, or *mock suns*, and those of the moon *paraselenæ*, or *mock moons*.

Glories, called *anthelia*, are sometimes seen to surround the shadow of an observer's head when cast on fog or cloud.

A most remarkable optical phenomenon was observed by the author on May 3d, 1882, opposite Henrietta Nesmith Glacier, Grinnell Land. A beautiful mock sun, accompanied by *clearly defined prismatic colors*, was seen against the only light clouds in the heavens, at a distance of about 120° from the sun.

Flammarion says of this rare and remarkable phenomenon: "Sometimes the solar rays experience two successive reflections upon the vertical surfaces of one of the prisms. There is then visible, at 120° from the sun, a white image more or less diffuse, which has received the name of *paranthelion*. The horizontal bars of the ice crystals reflect also the solar light, but in an upward direction, which prevents the spectator from perceiving it unless he be on the summit of a steep mountain or in the car of a balloon, above the cloud containing the icy particles. It will be readily admitted that these conditions can rarely be fulfilled; but MM. Barral and Bixio were fortunately able to realize them on July 27th, 1850. The image of the sun thus reflected appears almost as luminous as the sun. Bravais suggested for this phenomenon, at once so remarkable and so rare, the name of *pseudohelion*."

Mirage is an image produced by the successive bending of rays of light in passing through the strata of air of varying densities. It is particularly frequent over dry, sandy wastes, and in the United States is not uncommon in the southwestern States and Territories. It is likewise common in the polar regions, especially across the open water to heavy ice or land. Remarkable stories, which the author, from his experience on land and sea, can well credit, have been told of travellers being led to believe these airy phantoms to be living lakes, extensive forests, and great cities.

AURORA BOREALIS.

The weird beauty and splendor of the aurora has always engaged the attention of mankind, awakening feelings of terror, awe, or admiration, according to the various views held by the populace regarding its cause and significance.

Until late years auroras have been considered as meteorological phenomena, but at the present time their active connection with weather changes is very problematical. While the auroral display is evidently a visible manifestation of the atmospheric electricity, yet in view of its limited range its appearance or non-appearance cannot be considered as having more than a local and transient meteorological interest.

The aurora is never seen in very low latitudes, rarely south of the fortieth parallel, and only infrequently to the northward of the 80° N. latitude. The aurora may be visible in the heavens either to the south or north, according to the locality of the observer, since the belt of its greatest frequency skirts Northern Asia, touches Southern Greenland, and crosses North America from Labrador to Behring Strait. This belt of frequency is substantially the portion of the northern hemisphere over which the greatest atmospheric disturbances and movements take place, and attempts, as yet unsuccessful, have been made to definitely determine that an intimate relation exists between such changes and these electrical phenomena.

A fuller treatment of the subject of auroras pertains rather to the phenomena of terrestrial magnetism than to meteorology.

CHAPTER XXI.

WEATHER PREDICTIONS.

A BRIEF allusion to the methods of weather predictions may be of some interest to the general reader. So firmly and widely rooted is the belief in the practicability of weather forecasting, that separate bureaus for this purpose have been formed and are maintained at public expense in the United States, Great Britain, France, Germany, Italy, Russia, Algeria, Australia, India, and Japan. Other nations, such as Sweden, Holland, and Switzerland, co-operate with and share the expenses and benefits of other larger countries.

The weather predictions made when the United States weather bureau was established, in 1870, were exceedingly vague and indefinite in their character, but in late years a marked change has been made in the methods followed and the clearness of predictions made. That which fifteen or twenty years ago seemed impossible or wonderful has become an every-day occurrence, and with the increasing knowledge of meteorology there has been a growing demand for absolute accuracy and definiteness.

All skilled meteorologists realize how comparatively local are weather conditions and how impossible it is at times to make predictions for a definite period with any feeling of certainty. Indeed, weather conditions vary so much that occasionally even the most skilled forecaster cannot say with absolute confidence what will be the coming weather for certain localities, even for a period of eight hours; while, again, the conditions are so definite and clear that one can foretell with a fair degree of confidence the weather for entire districts and for periods of even forty-eight or seventy-two hours in advance.

The forecaster, then, has to bear in mind that weather conditions are largely local, and so he must study with such fact prominently in view. Indeed, so local is the weather of many States of the Union, that one cannot even attain for any prolonged period a higher percentage of *accuracy* than ninety in describing *briefly* the weather changes of the *past* twenty-four hours. The accuracy of this statement may be illustrated by the fact that in 1886 predictions of rain, if made with absolute correctness for Western Pennsylvania, based on Pittsburg, would have been ten per centum in error for Erie, Pa. In like manner the records show that rain fell in Eastern Iowa on twelve per centum more days at Dubuque than at Davenport; in Tennessee, sixteen per centum more at Knoxville than at Nashville; in Eastern Michigan, nineteen per centum more at Alpena than at Port Huron, and in Northern Georgia the difference amounts to twenty-one per centum between Atlanta and Augusta. The forecaster, then, even for districts of moderate size, cannot expect that predictions of rain will be equally successful in all portions of the section predicted for. It is evident that fair-weather conditions are those which are most persistent and from the prediction of which the highest percentages of accuracy will be obtained. But if more difficult of verification, yet rain predictions are more important to the public, and so should be made more freely than the reverse.

The skill of a weather predictor arises largely from his alert comprehensiveness of mind, accurate and retentive memory, phlegmatic but confident temperament, and long experience in connection with the discussion of storms for the section of the globe and the period of the year for which he predicts. The first of these qualities enables him to instantly grasp the situation and promptly draw correct general inferences from slight indications, as does the skilled physician in diagnosing obscure cases; the second renders it possible for him to recall, with their sequence, similar weather conditions—a very important matter—when they are typical; the third enables him to maintain unimpaired his confidence in his own ability and judgment when he has made a series of unsuccessful predictions. Experience, the last but not the least, is most necessary, since the attendant circumstances of storms change so materially, even from one season of the year to another, that a forecaster skilled in summer storms may fail at first in discussing those of the winter. To these qualities may be added the necessity of an imaginative or creative faculty, since the configuration and physical outlines of a country have such important bearings upon the development, progress, and movement of storms as to render it essential that the predictor shall have the country, as it were, actually before his eye, instead of the flat map on which the data is charted.

The official may know and predict accurately the general direction in which a storm will move, and yet in thickly populated countries, such as the northeastern part of the United States, the passage of a storm only twenty miles to the northward or southward of the point fixed in advance by the forecaster will result in weather conditions which must disappoint hundreds of thousands of people who are interested in them. This narrow difference of a few miles in predicting twenty-four hours in advance the path of a storm which travels 600 or 700 miles daily is almost infinitesimal as regards the storm path itself, and yet it is sufficient to produce cold, northerly winds, with snow, in place of warm, southerly winds, with rain, or *vice versa.*

A few general rules for weather predictions in the United States, based largely on the author's personal labors in forecasting, may be interesting, as supplementary to general statements made in previous pages, and as of practical value when considering doubtful and uncertain weather conditions.

1. In case of doubt, and when the temperature is abnormally high or low, it is safest to assume that the temperature will tend to return to its normal and seasonal condition.

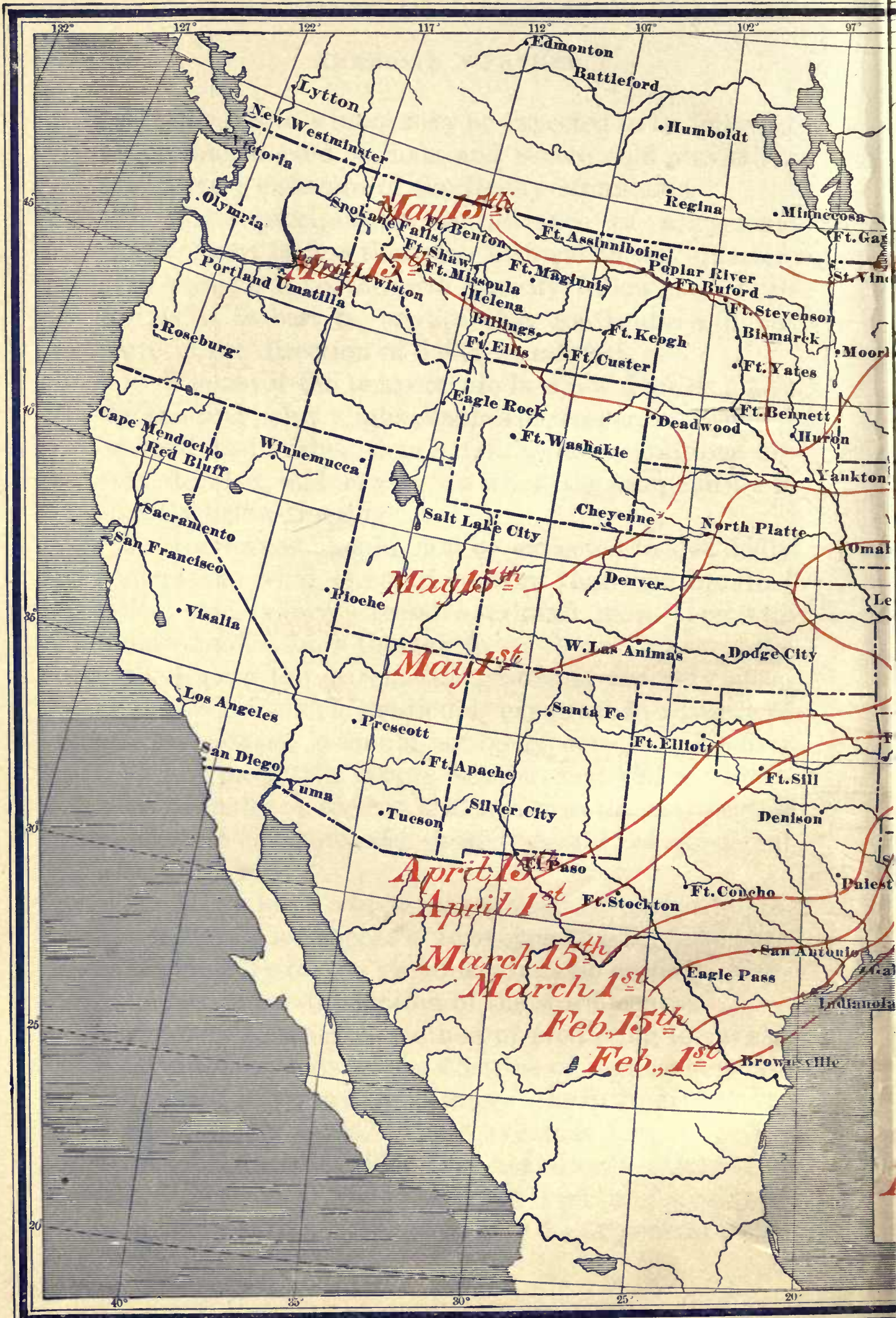
2. When the winds along the Gulf coast or Atlantic seaboard have blown from the ocean for twenty-four hours, even if the cloud formations are not large, rain may be assumed, with considerable accuracy, to follow within the ensuing day.

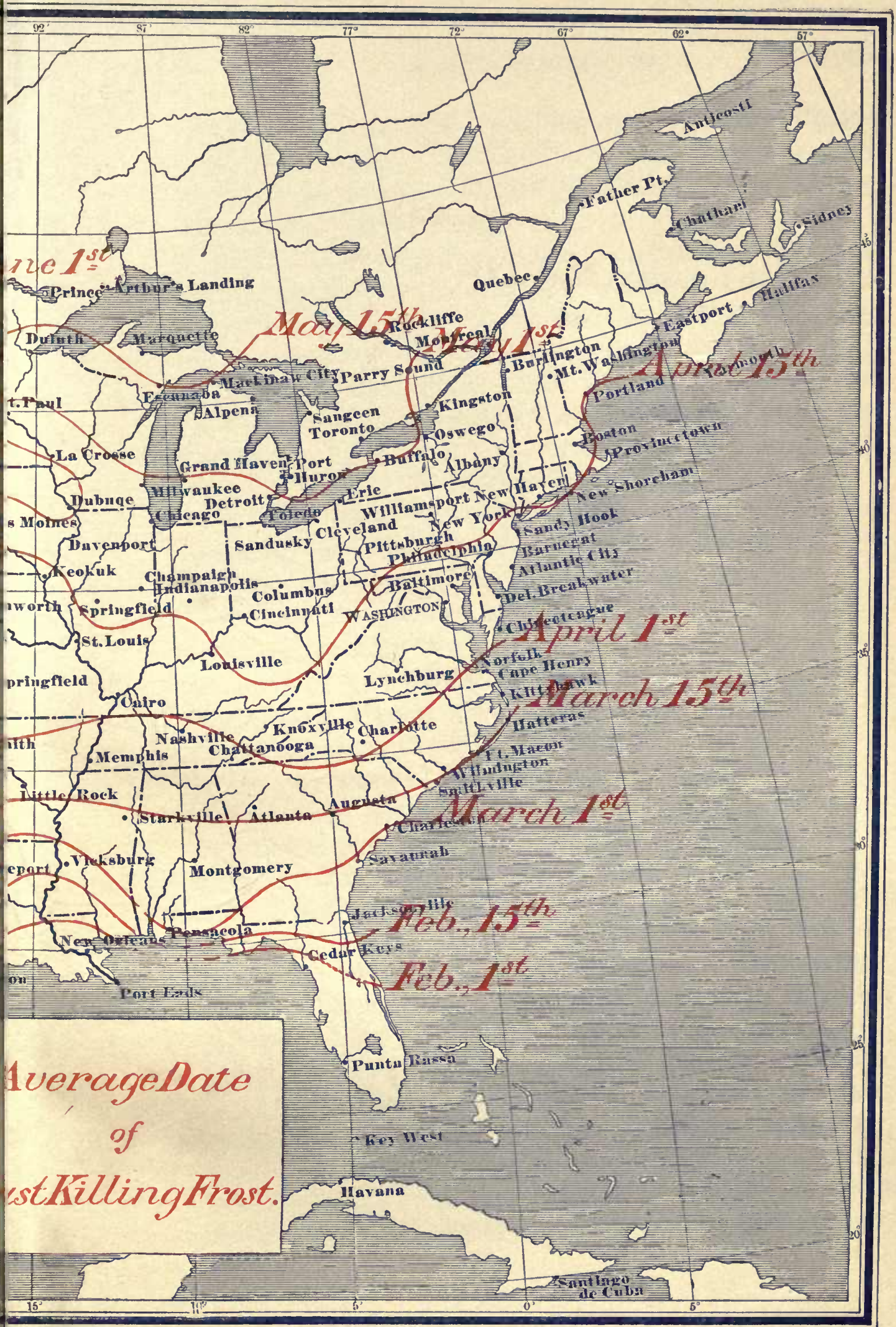
3. Whenever the United States is covered with a barometric pressure below the normal, and no sharply-defined storm centre is present, the chances predominate that existing weather conditions will drift slowly, and with slight changes, from the Mississippi Valley to the Atlantic coast.

4. Whenever in uncertain conditions the barometer rises in the southwestern part of the United States, the weather to the north and east will soon clear, without there are decided and obvious reasons to the contrary.

5. Cyclonic storms which enter the United States to the westward of the Mississippi River rarely recurve to the eastward, but may be expected to pass inland and die out within the confines of the continent.

6. Cyclonic storms, with paths entirely or largely in


132°
127°
122°
117°
112°
107°
102°
97°
Edmonton
Battleford
Humboldt
Lytton
New Westminster
Victoria
Regina
Minnecosa
Olympia
Spokane Falls
May 15th
Ft. Benton
Ft. Assinniboine
Ft. Shaw
Ft. Missoula
Ft. Maginnis
Poplar River
Ft. Buford
May 15th
Portland
Umatilla
Lewiston
Helena
Ft. Stevenson
Billings
Bismarck
Ft. Keogh
Roseburg
Ft. Ellis
Ft. Custer
Ft. Yates
Eagle Rock
Ft. Bennett
Deadwood
Huron
Cape Mendocino
Red Bluff
Winnemucca
Ft. Washakie
Yankton
Sacramento
Salt Lake City
Cheyenne
North Platte
San Francisco
Denver
May 15th
Pioche
Visalia
W. Las Animas
Dodge City
May 1st
Los Angeles
Santa Fe
Prescott
Ft. Elliott
San Diego
Ft. Apache
Ft. Sill
Yuma
Silver City
Tucson
Denison
April 15th
El Paso
Ft. Concho
April 1st
Ft. Stockton
March 15th
San Antonio
March 1st
Eagle Pass
Indianola
Feb. 15th
Feb., 1st
45
40
35
30
25
20
40°
35°
30°
25°
20°


AverageDate
of
…stKillingFrost.
…une 1st
May 15th
May 1st
April 15th
April 1st
March 15th
March 1st
Feb., 15th
Feb., 1st
Anticosti
Father Pt.
Chatham
Sidney
Quebec
Halifax
Eastport
Prince Arthur's Landing
Duluth
Marquette
Rockliffe
Montreal
Burlington
Mt. Washington
Yarmouth
Portland
Mackinaw City
Parry Sound
Escanaba
Alpena
Kingston
Sangeen
Toronto
Oswego
Boston
Provincetown
La Crosse
Grand Haven
Port Huron
Buffalo
Albany
New Haven
New Shoreham
Milwaukee
Detroit
Erie
Dubuque
Chicago
Toledo
Williamsport
New York
Sandy Hook
Cleveland
Davenport
Sandusky
Pittsburgh
Philadelphia
Barnegat
Atlantic City
Keokuk
Champaign
Indianapolis
Columbus
Baltimore
Del. Breakwater
Springfield
Cincinnati
WASHINGTON
Chincoteague
St. Louis
Louisville
Norfolk
Cape Henry
Lynchburg
Kittyhawk
Cairo
Hatteras
Knoxville
Charlotte
Nashville
Chattanooga
Memphis
Ft. Macon
Wilmington
Smithville
Little Rock
Augusta
Starkville
Atlanta
Charleston
Savannah
Vicksburg
Montgomery
Jacksonville
Pensacola
New Orleans
Cedar Keys
Port Eads
Punta Rassa
Key West
Havana
Santiago de Cuba
92°
87°
82°
77°
72°
67°
62°
57°
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°
5°

orological conditions. Of this character are Charts XXII. and XXIII., which show, respectively, the average date of the last killing frost and of the first killing frost in the United States.

Table No. 9 shows how large a proportion of the frosts at varying stations have occurred within ten days of the average date, so that the value of this class of data may be easily determined by the reader.

In like manner, Charts Nos. IX. and X. may be used in determining the probable chances of such crops maturing as are dependent on continued daily mean temperatures above 32° and 50° Fahrenheit.

In connection with these charts, the agriculturist or other persons interested should use their own knowledge of local meteorology to supplement these data.

It may be well to here add a simple and definite method by which in clear, cool weather, near the period of early or late frosts, a person interested may determine, with a very considerable degree of accuracy, if frost will occur the following night.

The approach of local frost can be foretold with very considerable accuracy from the readings of properly exposed *dry* and *wet* thermometers. A safe and simple rule to follow when the temperature is at 50° or below is to multiply the difference between the readings of the thermometers by 2.5, and when the sum thus obtained is subtracted from the reading of the dry thermometer, it leaves the approximate degrees to which the temperature of the air will fall the coming night, unless change of wind to a moister quarter or increase of cloudiness interferes. The value and importance of observations of this kind have not been sufficiently impressed upon farmers cultivating crops of a kind susceptible to frost and capable of protection. This subject has been erroneously viewed by many as too abstruse and complex for practical application by unscientific persons. Since this lowering of temperature is caused by radiation, it follows that any method which will prevent free radiation must materially check the formation of frost, so that even thin cloth, layers of straw, or even a cloud of smoke will protect tender plants, unless the frost is very severe.

The question is often broached as to whether weather conditions for the coming month or season can be foretold. There is evidently a general and widespread interest in this question, since on the desire for and belief in such long-range predictions has rested the ephemeral notoriety of many weather prophets. It is a general scientific admission that as yet the advances of meteorology are insufficient to justify predictions of the weather for a season in advance. There are apparently good grounds for believing that general laws can be deduced by which for certain parts of the globe it will be possible, from abnormal distributions of atmospheric pressure, to predict for prolonged periods in advance the general character of the coming season, as warm or cold and wet or dry. Unfortunately for America, it seems that, owing to the easterly drift of the atmosphere, the ultimate chances of such predictions are better for Europe and Asia than for this continent.

The question of cyclical variation of rainfall coincident with sun-spots has been very fully discussed by Blanford, so far as India is concerned. He points out the peculiar fascination such theories exert over many minds, and he emphasizes the necessity for rigorous scrutiny of all such cycles by a general array of facts. He quotes from Russell in New South Wales to show that cycles for periods of two, three, five, six, nine, ten, eleven, twelve, thirteen, seventeen, nineteen, thirty, and fifty-six years have been brought forward with a large amount of *prima facie* evidence.

Blanford examined the rainfall of all India for twenty-two years, and in arranging the rainfall in the biennial, triennial, etc., up to quinquennial series, he "found that the cyclical series could always be brought out, but this amplitude proved nothing very different from the probable error of the average." After elaborately discussing the rainfall of India as a whole for two complete sun-spot cycles, Mr. Blanford says: "It may therefore be confidently concluded that the total rainfall of India, exclusive of that of Ceylon and the Burmese peninsula, and (of course) of the seas around, affords no evidence whatever of an eleven-year periodical variation."

An examination of the annual mean anomaly of the total rainfall of India for twenty-one years, 1864 to 1885, inclusive, indicates that such variations are accidental in India at least.

A comparison of the rainfall of separate provinces shows that in 1871, a maximum sun-spot year, the precipitation of the Konkan was 14.6 inches deficient, while that of Malabar was 2.4 inches in excess. In ten years only out of eighteen did the four rainfall provinces of India have the same sign to its annual deviation.

A similar theory as to the prevalence of droughts in the years of minimum sun-spots and of heavy rain at the sun-spot maximum has found many supporters. Blanford has compared the record of sun-spots and droughts, and makes the definite statement that there is no "dependence of the one class of phenomena on the other," since the record shows that not only do droughts occur in India at other times than at the sun-spot maximum, but even "sometimes in years of maximum sun-spots."

In connection with the theory that the temperature of the air is subject to variations running in periods of about eleven years, in inverse order to the number of sun-spots, Blanford has examined the temperature of India for thirty-one years, from 1850 to 1880, inclusive. He says: "It is evident that there is no indication whatever of an eleven-year period, or any other, in the temperature anomalies" of India.

The author has examined, with reference to the influence of sun-spots upon precipitation, the following representative stations: San Francisco, Cal.; St. Louis, Mo.; Marietta, O.; Troy, N. Y., and Gardiner, Me., from 1857 to 1887; Cheyenne, Wy., 1870 to 1886; and Omaha, Neb., 1870 to 1887.

These stations were selected, as, from their widely varying longitude, they might be expected to be representative stations, covering the whole area of the United States. There was only one year in which the departures of these stations had the same sign, 1864, when there was a deficiency of rainfall at five stations. In 1866, near the minimum sun-spots, there was an excess of rainfall at four stations and a deficiency at one; in 1870, the year of the maximum sun-spots, there was a deficiency at four stations and an excess at one; in 1874, a deficiency at five and an excess at one; in 1875 an excess at four and a deficiency at three; in 1876, an excess at two and a deficiency at five; in 1878, a year of maximum sun-spots, an excess at five and a deficiency at two; in 1880, an excess at two and a deficiency at five; in 1884, an excess at five and a deficiency at two.

The rainfall data at these stations showed no connection with the periodicity of sun-spots, and any apparent connection between them is, in the opinion of the author, entirely accidental.

TABLE NO. 1.—CORRECTION TO BE APPLIED TO BAROMETERS WITH BRASS SCALES, TO REDUCE THE OBSERVATION TO 32° FAHRENHEIT.

Temperature.	Inches.					
	25.0	27.0	29.0	29.5	30.0	30.5
°	+	+	+	+	+	+
20	.019	.021	.022	.023	.023	.023
28	.001	.001	.001	.001	.001	.001
	—	—	—	—	—	—
29	.001	.001	.001	.001	.001	.001
30	.003	.004	.004	.004	.004	.004
35	.015	.016	.017	.017	.018	.018
40	.026	.028	.030	.030	.031	.031
45	.037	.040	.043	.044	.044	.045
50	.048	.052	.056	.057	.058	.059
52	.053	.057	.061	.062	.063	.064
54	.057	.062	.066	.067	.068	.070
56	.061	.066	.071	.073	.074	.075
58	.066	.071	.077	.078	.079	.081
60	.070	.076	.082	.083	.085	.086
62	.075	.081	.087	.088	.090	.091
64	.079	.086	.092	.094	.095	.097
66	.084	.090	.097	.099	.101	.102
68	.088	.095	.102	.104	.106	.108
70	.093	.100	.108	.109	.111	.113
72	.097	.105	.113	.115	.117	.119
74	.102	.110	.118	.120	.122	.124
76	.106	.114	.123	.125	.127	.129
78	.110	.119	.128	.130	.133	.135
80	.115	.124	.133	.136	.138	.140
82	.119	.129	.138	.141	.143	.146
84	.124	.134	.144	.146	.149	.151

TABLE NO. 2.—TABLE FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA-LEVEL, CORRECTION ADDITIVE.

HEIGHT IN FEET.	TEMPERATURE OF EXTERNAL AIR—DEGREES FAHRENHEIT.									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
10	.012	.012	.012	.012	.011	.011	.011	.011	.010	.010
20	.025	.024	.023	.023	.023	.022	.022	.021	.021	.020
30	.037	.036	.035	.034	.034	.033	.032	.032	.031	.030
40	.049	.048	.047	.046	.045	.044	.043	.042	.041	.040
50	.061	.060	.059	.058	.056	.055	.054	.053	.052	.051
60	.074	.072	.070	.069	.068	.066	.065	.063	.062	.061
70	.086	.084	.082	.081	.078	.077	.076	.074	.072	.071
80	.098	.096	.094	.092	.090	.088	.086	.084	.082	.081
90	.111	.108	.105	.104	.101	.099	.097	.095	.093	.091
100	.123	.120	.117	.115	.112	.110	.108	.105	.103	.101
150	.185	.180	.176	.172	.168	.165	.162	.158	.155	.152
200	.246	.240	.234	.229	.224	.220	.215	.210	.206	.202
250	.307	.300	.293	.286	.280	.275	.269	.263	.258	.253
300	.368	.359	.351	.343	.336	.329	.322	.315	.309	.303
350	.429	.419	.409	.400	.392	.384	.376	.368	.360	.353
400	.489	.478	.467	.457	.447	.438	.429	.420	.411	.403
450	.550	.537	.525	.513	.503	.492	.482	.472	.462	.453
500	.610	.596	.583	.570	.558	.546	.535	.524	.513	.503
550	.670	.655	.640	.626	.613	.600	.587	.575	.564	.553
600	.731	.714	.698	.683	.668	.654	.640	.627	.615	.603
650	.791	.773	.755	.739	.723	.708	.692	.679	.666	.653
700	.851	.882	.813	.795	.778	.761	.745	.730	.716	.702
750	.911	.891	.870	.851	.833	.815	.797	.782	.767	.752
800	.970	.949	.927	.907	.887	.868	.850	.833	.817	.801
850	1.030	1.007	.984	.962	.942	.922	.902	.885	.867	.851
900	1.089	1.065	1.041	1.018	.996	.975	.955	.936	.917	.900
1,000	1.208	1.181	1.154	1.129	1.105	1.081	1.059	1.038	1.017	.998
1,100	1.326	1.296	1.267	1.239	1.213	1.187	1.163	1.140	1.117	1.096
1,200	1.444	1.411	1.379	1.349	1.321	1.293	1.266	1.241	1.217	1.193
1,300	1.561	1.525	1.491	1.459	1.428	1.398	1.369	1.342	1.316	1.290
1,400	1.678	1.639	1.603	1.568	1.535	1.503	1.472	1.443	1.415	1.387
1,500	1.794	1.753	1.714	1.677	1.641	1.607	1.574	1.543	1.513	1.484

TABLE NO. 3.—APPROXIMATE CORRECTIONS TO REDUCE BAROMETER READINGS AT 8 A.M. AND 8 P.M., 75TH MERIDIAN OR EASTERN TIME TO THE DAILY MEAN.

	8 A.M.	8 P.M.
Augusta, Ga.	— .02 inch	+ .01 inch
Bismarck, Dak.	— .02 "	+ .02 "
Boston, Mass.	— .02 "	+ .00 "
Buffalo, N. Y.	— .02 "	+ .01 "
Chicago, Ill.	— .02 "	+ .02 "
Cincinnati, O.	— .02 "	+ .01 "
Denver, Col.	— .02 "	+ .03 "
Key West, Fla.	— .01 "	+ .01 "
Memphis, Tenn.	— .03 "	+ .03 "
Montgomery, Ala.	— .04 "	+ .03 "
New Orleans, La.	— .03 "	+ .02 "
Portland, Ore.	— .01 "	+ .03 "
Salt Lake City, Utah.	— .02 "	+ .03 "
San Diego, Cal.	+ .01 "	+ .02 "
San Francisco, Cal.	+ .01 "	+ .02 "
Washington, D. C.	— .03 "	+ .01 "

TABLE NO. 4.—*APPROXIMATE* CORRECTIONS FOR REDUCING THE MEAN OF THE MAXIMUM AND MINIMUM TEMPERATURES TO THE TRUE MEAN OF THE DAY.

	January.	July.
San Diego, Cal.	— 0.7°	— 0.3°
Toronto, Canada*	— 0.4°	— 0.1°
Washington, D.C.	— 0.9°	— 0.8°
Denver, Col.	— 0.1°	— 0.8°
Savannah, Ga.	— 0.0°	— 0.2°
Frankfort Arsenal, Pa.*	— 0.8°	— 0.1°

* From Guyot's Tables.

TABLE NO. 5.—SHOWING VAPOR TENSIONS AND ABSOLUTE HUMIDITIES FOR DEW-POINTS OF VARIOUS TEMPERATURES.

Dew-point Temperature.	Vapor Tension.*	Absolute Humidity, Grains of Water to each Cubic Foot.	Dew-point Temperature.	Vapor Tension.	Absolute Humidity, Grains of Water to each Cubic Foot.
— 40°	0.01	.08	56°	0.45	5.02
— 30	.01	.13	58	.48	5.37
— 20	.02	.22	60	.52	5.75
— 10	.03	.36	62	.56	6.14
0	.04	.56	64	.60	6.56
10	.07	.87	66	.64	7.01
20	.11	1.32	68	.68	7.48
30	.17	1.96	70	.73	7.98
35	.20	2.37	72	.78	8.51
40	.25	2.85	74	.84	9.07
45	.30	3.42	76	.90	9.66
50	.36	4.08	78	.96	10.28
52	.39	4.37	80	1.02	10.94
54	.42	4.69	90	1.41	14.79

* For considerable elevations about .01 should be added for each thousand feet.

TABLE NO. 6.—MAGNETIC VARIATIONS IN 1888.

Variation *east* is when the compass points to the *east* of the true north.

Variation East.	Degrees.	Minutes.	Variation West.	Degrees.	Minutes.
Bismarck, Dak	15	35	Boston, Mass	11	55
Brownsville, Tex....	7	35	Buffalo, N. Y........	5	10
Chicago, Ill..........	4	00	Charleston, S. C.....	0	00
Denver, Col...........	14	15	Cleveland, O.........	1	35
El Paso, Tex.........	12	00	Detroit, Mich	0	30
Helena, Mont.........	19	55	Eastport, Me.........	18	55
Jacksonville, Fla....	2	00	Lynchburg, Va.......	1	25
New Orleans, La....	6	00	New York City......	8	20
Olympia, Wash. Ty..	21	40	Northfield, Vt.......	12	50
Omaha, Neb.........	10	10	Pittsburg, Pa........	3	00
San Diego, Cal.......	13	35	Washington, D. C...	4	10
San Francisco, Cal...	16	35	Wilmington, N. C...	0	50

TABLE NO. 8.—HEAVIEST MONTHLY RAINFALLS EVER RECORDED IN THE VARIOUS STATES.

STATE.	Station.	Month.	Year.	Rainfall in Inches.
Alabama	Opelika	July	1887	20.13
Arizona	Camp Goodwin	August	1880	14.45
Arkansas	Lead Hill	October	1883	18.11
California	Upper Matole	January	1888	41.60
Colorado	Trinidad	June	1878	12.83
Connecticut	Canton	May	1868	18.00
Dakota	Webster	July	1884	14.65
Delaware	Fort Delaware	September	1868	19.85
District of Columbia.	Washington	July	1886	10.63
Florida	Ft. Barrancas	August	1878	30.73
Georgia	Raburn Gap	October	1877	19.40
Idaho	Lewiston	June	1884	5.63
Illinois	Cairo	January	1876	15.05
Indiana	Indianapolis	July	1875	13.12
Indian Terr.	Fort Gibson	July	1875	11.89
Iowa	Rockford	June	1885	18.70
Kansas	Elk Falls	April	1885	19.00
Kentucky	Louisville	July	1875	16.46
Louisiana	Alexandria	June	1886	36.91
Maine	Eastport	May	1881	13.22
Maryland	St. John's Church.	May	1881	12.30
Massachusetts	Amherst	July	1874	12.61
Michigan	Northport	May	1884	19.85
Minnesota	Sylvan Park	July	1872	21.86
Mississippi	Jackson	April	1874	23.80
Missouri	St. Louis	June	1848	17.07
Montana	Fort Ellis	June	1885	12.26
Nebraska	Table Rock	June	1883	17.07
Nevada	Fort McDermit	April	1883	13.00
New Hampshire	Mt. Washington	July	1884	23.90
New Jersey	Newark	August	1843	22.50
New Mexico	Fort Union	August	1886	8.04
New York	Troy	October	1869	13.80
North Carolina	Asheville	August	1887	28.65
Ohio	Carthagena	June	1877	17.33
Oregon	Astoria	January	1880	29.80
Pennsylvania	Wellsboro	August	1885	15.25
Rhode Island	Block Island	June	1881	12.93
South Carolina	Charleston	August	1885	19.18
Tennessee	White	July	1883	28.11
Texas	Brownsville	September	1886	30.57
Utah	Mt. Carmel	March	1877	10.00
Vermont	Craftsburg	October	1869	10.72
Virginia	Cape Henry	August	1887	16.82
Washington Terr.	Neah Bay	December	1886	30.70
West Virginia	Helvetia	August	1882	12.60
Wisconsin	Neillsville	September	1881	14.01
Wyoming	Hat Creek	April	1879	6.93

TABLE NO. 7.—HIGHEST AND LOWEST TEMPERATURES, WITH MONTH AND YEAR IN WHICH OBSERVED, AT SIGNAL SERVICE STATIONS IN EACH STATE.

State.	Highest. Place.	Highest. Degrees.	Highest. Date.	Lowest. Place.	Lowest. Degrees.	Lowest. Date.
Alabama	Montgomery	106.9	July, 1881	Montgomery	54	January, 1886.
Arizona	Fort McDowell*	119	June, 1887	Prescott	— 18	December, 1879.
Arkansas	Fort Smith	104.5	August, 1886; July, 1884	Fort Smith	— 6.9	January, 1886.
California	Red Bluff	111.5	July, 1887	Fort Bidwell	— 25.5	January, 1888.
Colorado	Las Animas	105.2	July, 1885	Denver	— 29	January, 1875.
Connecticut	New Haven	100	September, 1881	New Haven	— 14	January, 1873.
Dakota	Fort Sully	111	June, 1874, 1876	Fort Buford	— 49.2	January, 1888.
Delaware	Del. Breakwater	98.1	August, 1885	Del. Breakwater	1	December, 1880.
District of Columbia	Washington	104.3	September, 1881	Washington	— 14	January, 1881.
Florida	Jacksonville	104	July, 1879	Pensacola	14.9	January, 1886.
Georgia	Augusta †	105	July, August, 1878	Atlanta	— 24	January, 1886.
Idaho	Fort Lapwai	115	August, 1882	Eagle Rock	— 38	January, 1883.
Illinois	Cairo	103	August, 1881	Chicago	— 23	December, 1872.
Indiana	Indianapolis	101	July, August, 1881	Indianapolis	— 25	January, 1884.
Indian Terr	Fort Gibson	109	July, 1879	Fort Reno	— 20	January, 1886.
Iowa	Des Moines	104.4	July, 1886	Dubuque	— 31.5	January, 1887.
Kansas	Dodge City	108	July, 1876	Leavenworth	— 29	January, 1873.

Kentucky	Louisville	104.6	August,	1881	Louisville	— 19.5	January,	1884.
Louisiana	Shreveport	107	July,‡	1875	Shreveport	1.3	January,	1886.
Maine	Portland	97	July,	1876	Eastport	— 21	December,	1884.
Maryland	Baltimore	101.8	July,	1887	Baltimore	— 6	January,	1881.
Massachusetts	Boston	101.5	September,	1881	Boston	— 13	January,	1882.
Michigan	Detroit	101	July,	1887	Mackinaw City	— 33.4	February,	1885.
Minnesota	St. Vincent	103.2	August,	1886	St. Vincent	— 53.5	January,	1888.
Mississippi	Vicksburg	101	June,	1881	Vicksburg	3.1	January,	1886.
Missouri	St. Louis	106.4	August,	1881	St. Louis	— 21.5	January,	1884.
Montana	Fort Benton	110.8	July,	1886	Poplar River	— 63.1	January,	1885.
Nebraska	North Platte	107	July,	1877	North Platte	— 34.6	January,	1888.
Nevada	Winnemucca	104	July,	1877	Winnemucca	— 28	January,	1888.
New Hampshire	Manchester	93.3*	July,	1887	Manchester	— 11	February,	1888.
New Jersey	Sandy Hook	101	September,	1881	Barnegat	— 10	January,	1875.
New Mexico	Fort Bayard	115	July,	1882	Fort Stanton	— 18.2	December,	1887.
New York	New York City;	100.2	September,	1881	Oswego	— 22.9	January,	1885.
North Carolina	Kitty Hawk	107.1	July,	1887	Charlotte	— 5	December,	1880.
Ohio	Cincinnati	103.5	July,	1881	Sandusky	— 28	February,	1884.
Oregon	Umatilla	110	August,	1882	Fort Klamath	— 39	January,	1888.
Pennsylvania	Pittsburg	102.7	July,	1881	Erie	— 16	January,	1875.
Rhode Island	Narragansett Pier.	92	July,	1885	Narragansett Pier.	— 9	December,	1884.
South Carolina	Charleston	104	July,	1875	Charleston	10.5	January,	1886.
Tennessee	Nashville	104	August,	1874	Knoxville	— 16	January,	1884.
Texas	El Paso	113	June,	1883	Fort Elliott	— 14.2	January,	1888.
Utah	Fort Thornburgh.	103.5	July,	1884	Salt Lake City	— 20	January,	1883.
Vermont	Burlington	97	August,	1876	Burlington	— 24.8	January,	1882.
Virginia	Cape Henry	103	August,	1881	Lynchburg	— 5	December,	1880.
Washington Terr.	Walla Walla	104	July,	1886	Spokane Falls	— 30.5	January,	1888.
West Virginia	Morgantown	97	July,	1874	Morgantown	— 10	February,	1875.
Wisconsin	La Crosse	101	July,	1874	La Crosse	— 42.0	January,	1888.
Wyoming	Cheyenne	100.5	July,	1881	Fort Washakie	— 53.5	February,	1883.

* Also Phœnix, 119°, June, 1883. † Also Savannah, 105°, July, 1879. ‡ Also August, 1881.

TABLE NO. 9.—AVERAGE DATES, ETC., OF FIRST KILLING FROST IN AUTUMN.

Station.	Number of Years, Record.	Average Date.	Earliest Recorded.	Extreme Interval, Days.	Latest Recorded.	Extreme Interval, Days.	Number of Times Interval was Ten Days or More.	Per cent of Times Interval was Less than Ten Days.
Washington, Ark	24	Oct. 28	Sept. 30	28	Nov. 16	19	9	62
Sacramento, Cal	23	Nov. 19	Oct. 17	33	Dec. 31	42	18	22
Middletown, Conn	29	Oct. 2	Sept. 10	22	Oct. 22	20	12	59
Forsyth, Ga	13	Nov. 8	Oct. 17	22	Nov. 25	17	3	77
Peoria, Ill	32	Oct. 27	Oct. 1	26	Nov. 17	21	11	66
Monticello, Ia	38	Sept. 17	Aug. 25	23	Oct. 13	26	16	58
Lawrence, Kan	18	Oct. 20	....	..	....	..	..	..
Gardiner, Me	29	Oct. 1	Sept. 4	27	Oct. 22	21	10	65
Amherst, Mass	47	Sept. 20	Aug. 10	41	Oct. 8	18	18	16
Holly Springs, Miss	32	Oct. 30	Oct. 10	20	Nov. 30	31	15	53
Oregon, Mo	33	Oct. 9	Sept. 17	22	Nov. 3	25	16	52
De Soto, Neb	17	Oct. 10	Sept. 24	16	Oct. 31	21	8	53
Cooperstown, N. Y	30	Sept. 27	Sept. 3	24	Oct. 22	25	13	57
Portsmouth, O.	44	Oct. 11	Sept. 11	30	Nov. 14	34	21	52
Bandon, Ore	14	Oct. 9	Sept. 9	30	Nov. 18	40	11	21
Dyberry, Pa	26	Sept. 23	Aug. 30	24	Oct. 21	28	9	65
New Ulm, Tex	12	Nov. 25	Nov. 12	13	Dec. 15	20	5	58
Lunenburg, Vt	28	Sept. 20	Aug. 5	46	Nov. 16	57	16	43
Dale Enterprise, Va	19	Oct. 2	Sept. 15	17	Oct. 31	29	7	63
Wytheville, Va	10	Sept. 19	Aug. 26	24	Oct. 14	25	5	50
Manitowoc, Wis	31	Oct. 16	Sept. 18	28	Nov. 13	28	17	45

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